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Filmwise Condensation of Steam on Horizontal
Wire-Wrapped Smooth and Roped Titanium Tubes

by

Thomas Joseph O'Keefe
Lieutenant, United States Navy
B.S., United States Naval Academy, 1986

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

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ABSTRACT

Filmwise condensation heat-transfer measurements were performed on horizontal smooth and roped titanium tubes using steam. The roped tubes were a commercially available tube (KORODENSE) with a nominal pitch of 7 mm. To further enhance the outside heat-transfer coefficient of both the smooth and roped tubes a wire was tightly wrapped around the tubes. To see the effect that the wire diameter and wire pitch had on the enhancement, 3 different wire diameters were used (nominal diameters of 0.5, 1.0, 1.6 mm) giving a range of wire pitch to wire diameter ratio of between 2 and 9. Tests were conducted under vacuum and atmospheric pressure conditions. The data reduction technique used the modified Wilson plot.

Results obtained for the wire-wrapped smooth titanium tubes showed a maximum enhancement of 30% as compared to a smooth titanium tube. This was for a tube using a 0.5 mm wire diameter ($P/D_w = 7.92$), corresponding to a fraction of the tube covered by the wire of 12%. The LPD KORODENSE titanium tube showed an enhancement of 20% as compared to a smooth titanium tube for both atmospheric and vacuum pressures. The addition of wrapping a wire in the grooves of the LPD tube showed no further significant enhancement for the three wire diameters tested.

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NOMENCLATURE

a	as defined in equation (4.23)
A_i	effective inside surface area, m^2
A_o	effective outside surface area, m^2
b	as defined in equation (4.22)
c	as define in equation (4.15)
C_1	leading coefficient for the inside heat transfer correlation used
C_p	specific heat at a constant pressure, J/kgK
d	as defined in equation (4.15)
D_i	tube inside diameter, m
D_o	tube outside diameter, m
E_T	enhancement ratio based on ΔT
F	fraction of the tube covered by wire
F^*	as defined in equation (2.3)
g	gravitational constant, 9.81 m/s
h_{fg}	specific enthalpy of vaporization, J/kg
h_i	inside heat transfer coefficient, W/m ² K
h_o	outside heat transfer coefficient, W/m ² K
k_c	thermal conductivity of the coolant film, W/mK
k_f	thermal conductivity of the condensate film, W/mK
k_m	thermal conductivity of the tube material, W/mK
K_1	as defined in equation (4.16)
K_2	as defined in equation (4.16)

L	active length of tube exposed to steam, m
L_1	length of inlet portion of tube, m
L_2	length of outlet portion of tube, m
LMTD	log mean temperature difference, K
$\dot{m}$	mass flow rate of the coolant, kg/s
Nu	Nusselt number
P_{sat}	saturation pressure, Pa
Pr	Prandtl number
Pr_w	Prandtl number at the wall temperature
Q	heat transfer rate, W
q	heat flux, W/m ²
Re	Reynolds number
Re_f	Reynolds number for the condensate film
$Re_{2\phi}$	two phase Reynolds number
R_i	inside thermal resistance, m ² K/W
R_o	outside thermal resistance, m ² K/W
R_{total}	total thermal resistance, m ² K/W
R_w	wall thermal resistance, m ² K/W
T_{cf}	temperature difference across the condensate film, K
ΔT_f	temperature difference across the film, K
T_{sat}	vapor saturation temperature, K
T_1	cooling water inlet temperature, K
T_2	cooling water outlet temperature, K
U_o	overall heat transfer coefficient, W/m ² K
U_∞	vapor velocity, m/s
V_w	velocity of the coolant, m/s

X	as defined in equation (4.19)
Y	as defined in equation (4.18)
Z	as defined in equation (4.12)

Greek Symbols

α	dimensionless coefficient
ϵ	as defined in equation (4.16)
μ_c	dynamic viscosity of the coolant, kg/m s
μ_f	dynamic viscosity of the condensate film, kg/m s
μ_w	dynamic viscosity of the condensate at the wall, kg/ms
ρ_f	density of the condensate film, kg/m ³
ρ_v	density of the vapor, kg/m ³
η	surface efficiency
Ω	as defined in equation (4.13)

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I. INTRODUCTION

A. BACKGROUND

Since the Cold War has ended, the money allocated for new weapon platforms in the Navy has been greatly reduced. There is therefore an increased emphasis on making ships as cost efficient as possible. Technology has progressed to the point where the heat removal requirements of modern weapons systems have increased. Future classes of attack submarines are expected to be smaller in size and just as capable as the existing 688 class. This will require the main and auxiliary propulsion systems to be designed for maximum power with the smallest, lightest, and most cost efficient components. One method to reduce the main propulsion system size and weight is to use enhanced tubing in the main condenser. In addition, submarine and surface ship refrigeration systems can have larger capacities, and maintain the same approximate size and weight if enhanced tubing is used in the refrigeration condenser. The Naval Postgraduate School, with support from the David Taylor Research Center, has been conducting research on various types of condenser tubing with the object of designing smaller, lighter, and more efficient condensers.

The DDG-51 class of destroyers was originally designed to have enhanced titanium tubes used for the refrigeration

condenser to give significant weight reduction to the refrigeration plant. In submarines, the use of enhanced titanium tubes in the main and auxiliary condensers would lead to a major reduction in weight of the steam propulsion plant. Titanium has the advantage over copper-nickel, which is presently used in condensers, of a higher strength to weight ratio, as well as excellent corrosion and erosion resistance. This allows for thinner tube walls and higher coolant flow rates to be used, so the same overall amount of heat can be transferred [Ref. 1]. The improved performance of enhanced tubes allows the same amount of power to be produced at a lower turbine backpressure, allowing for the design of smaller, more efficient propulsion plants. Alternatively, a larger power output can be achieved at the same backpressure for a plant of the same size. Some of the disadvantages of titanium are that it has a much smaller thermal conductivity and it is very expensive compared to copper-nickel.

B. CONDENSATION

Condensation occurs when a vapor is cooled below its saturation temperature, or when a vapor/gas mixture is cooled below its dew point. Condensation also occurs when a vapor comes into contact with a subcooled liquid. This is known as direct contact condensation. The most common type of condensation involved with heat exchangers is surface condensation. This occurs when the vapor contacts a surface

that is maintained below the saturation temperature of the vapor. Two types of surface condensation can take place. The first is filmwise condensation, so called because the condensate "wets" the surface with a continuous film. The second is dropwise condensation, so called because the condensate does not "wet" the surface, but instead forms distinct droplets of various sizes. Microscopic droplets coalesce to form large drops, which are then removed from the surface by gravity and/or vapor shear forces. Dropwise condensation results in much higher heat transfer coefficients (typically by an order of magnitude) than with filmwise condensation due to the fact that a certain portion of the cooled metal surface is exposed to the vapor. However, dropwise condensation is difficult to maintain over the life of a typical condenser. Many attempts have been made to promote dropwise condensation by using special surface coatings, but these tend to get 'washed' off in the little long term, reverting back to filmwise condensation. Therefore, condensers are normally designed to operate assuming filmwise condensation takes place, Thus providing for a conservative design [Ref. 2].

The heat transfer rate across a condenser tube is controlled by the tube wall, fouling, coolant side, and vapor side thermal resistances. For most laboratory experimental work, the tubes are thoroughly cleaned before testing, so the fouling thermal resistance is negligible. The other thermal

resistances vary depending on the condensing and coolant fluids used, tube geometry and material, and the flow conditions of the coolant and vapor. During condensation of steam, the coolant side thermal resistance is usually the dominant controlling resistance.

Methods of lowering the coolant side resistance include the use of inserts and roped tubes. However, any increase in heat transfer is offset by an increase in the pressure drop along the tube. Although inserts provide the best enhancement, the large pressure drop involved generally restricts their use to laminar flows and other specialist applications. Roped tubes, which tend to incur a much lower pressure drop, have been used successfully in a large scale condenser at the Gallatin Unit 1 300-MW power plant for the Tennessee Valley Authority. Low pressure drop (LPD) KORODENSE 90-10 Cu-Ni tubes were used to retube the condenser in August 1980 (LPD KORODENSE is a particular type of roped tube made by the Wolverine Tube Co.). Although it cost about \$65,000 more to retube using the roped tubes, a projected savings of \$908,000 is expected over the remaining life of the plant based on actual performance [Ref. 3]. The wall resistance is controlled by the type of material used and the thickness of the tube wall.

The vapor side thermal resistance is lowered essentially by thinning the condensate film. One way of thinning the condensate film can be achieved by changing the geometry of

the outside surface of the tube to utilize the surface tension effects of the fluid. Thinning the condensate film can significantly increase the heat transfer, especially for fluids like water where the surface tension is high. The use of fins, wire-wrap, and roped tubes have all been used to lower the vapor side resistance by causing an uneven pressure distribution through the condensate film on the surface of the tube.

C. CONDENSATION RESEARCH AT THE NAVAL POSTGRADUATE SCHOOL

The Naval Postgraduate School (NPS) has been conducting condensation research on enhanced tubes since 1982. Van Petten [Ref. 4] provides a summary of the research efforts on single horizontal tube condensation at NPS from 1982 to 1988. In particular, the research has looked at many aspects of enhancing tubes with low integral fins. Previous researchers have varied the fin spacing, fin shape, fin material, and tube diameter to determine how the performance of the tube is affected. Work has been done on single tubes and tube bundles at various pressures. Several different types of working fluids have also been used: steam, R-113, and ethylene glycol. All of this has been done to determine if the performance of an enhanced tube can be predicted, and under what condition the maximum enhancement will be realized.

Previously, the modified Wilson plot technique has been used to find the outside heat-transfer coefficient. However,

without an accurate inside heat transfer correlation, past researchers have had trouble reducing their data to provide an accurate value of the outside heat-transfer coefficient. Swensen [Ref. 5] used an instrumented tube to find the values of the tube wall temperatures. With a mean wall temperature of the tube, the inside and outside heat-transfer coefficients could be calculated directly. He then developed several inside heat transfer correlations using his data, based on the form of the Sieder-Tate [Ref. 6] correlation. His research noted that the outside heat transfer correlations were very sensitive to the Reynolds number exponent.

1. Condensation Research Using Roped and Wire-Wrapped Tubes

Most of the single tube condensation research done previously at NPS has involved the use of smooth and low integral fin copper tubes. Only a few researchers at NPS have studied the effects of wire-wrapping smooth tubes in a condensation application. The first was Kanakis [Ref. 7] in 1983. He tested titanium smooth and roped tubes, both with and without wire wrapping, while condensing steam in a vertical in-line tube bundle; up to 30 tubes were simulated by using inundation tubes. Brower [Ref. 8] used the same apparatus as Kanakis to try and determined the effects of wire diameter and pitch on the steam side heat transfer coefficient and to compare the effect of condensate inundation on smooth

and wire-wrapped tubes. Kanakis and Brower showed that the wire-wrapped tubes were not significantly affected by inundation (i.e. the wire provided better drainage down the bundle) in a steam condenser bundle. In a different apparatus, Mitrou [Ref. 9] conducted research on single tubes, both finned and wire-wrapped. He studied the relationship between the wire pitch and wire diameter for several wire-wrapped smooth copper tubes. Mitrou's results showed that the enhancement of a wire-wrapped tube compared to a smooth tube could be as much as 80% for the same temperature drop across the condensate film. The largest enhancements corresponded to a P/D_w ratio of between 5 and 7.

D. OBJECTIVES

The main objectives of this thesis were:

1. To find an accurate inside heat-transfer correlation, which is not sensitive to the Reynolds number exponent, for use in the data reduction technique.
2. To manufacture and collect condensation data on a series of titanium wire-wrapped smooth and roped tubes.
3. To check the repeatability of results of past researchers on the enhancement in the outside heat transfer coefficient due to wire-wrapping a copper tube.
4. To determine any effect of wire pitch and wire diameter on the enhancement in the outside heat transfer coefficient as compared to a smooth tube.

II. LITERATURE SURVEY

A. INTRODUCTION

When filmwise condensation occurs on a smooth horizontal tube, a thin condensate film forms around the tube. This condensate film provides a resistance to the heat transfer across the tube, so if the thickness of the film can be reduced, then the heat transfer rate will increase. To reduce the thickness of the film, several different methods have been used including low integral fins, wire-wrapped, and roped tubes. In the past, it was thought that enhancing a tube in this way for steam condensation would be impractical because the high surface tension would cause condensate to be retained between the surface enhancement on the tube, degrading performance.

The Naval Postgraduate School has conducted extensive research in enhancing the heat transfer performance of condenser tubes. The direction of the experimental research recently has been to find the optimum tube for condensation using the various enhancement methods.

B. FILM CONDENSATION OF STEAM ON A SMOOTH TUBE

In 1916, Nusselt [Ref. 10] showed that for a quiescent vapor condensing on a horizontal tube, the thickness of the condensate film varied around the tube. This variation led to

a variation in the local heat transfer coefficient, being a maximum at the top of the tube where the film is the thinnest. Nusselt's theoretical result for the mean heat transfer coefficient of a pure saturated vapor on a horizontal cylinder was:

$$h_o = 0.728 \left[\frac{k_f^3 \rho_f (\rho_f - \rho_v) g h_{fg}}{\mu_f D_o \Delta T_f} \right]^{1/4} \quad (2.1)$$

Nusselt's equation has been verified experimentally for a stationary vapor surrounding the tube. However, in most steam surface condensers, the vapor is moving with some velocity. The velocity of the vapor affects the thickness of the condensate film due to the drag imparted on it by the vapor. Shekriladze and Gomelaui (1966) [Ref. 11] took this surface shear into account and derived the following theoretical equation for the mean Nusselt number (dimensionless mean heat transfer coefficient):

$$\frac{Nu}{Re_{2\theta}^{1/2}} = 0.64 (1 + (1 + 1.69 F^*)^{1/2})^{1/2} \quad (2.2)$$

where:

$$F^* = \frac{Pr}{Fr Ph} = \frac{g D_o \mu_f h_{fg}}{U_\infty^2 k_f \Delta T_f} \quad (2.3)$$

$$Re_{2\theta} = \frac{\rho_f U_\infty D_o}{\mu_f} = \text{two phase Reynolds number}$$

F^* is a dimensionless parameter which relates the gravity force to the shear force. At high values of F^* , where gravitational forces dominate, equation (2.2) reduces to the Nusselt equation shown in equation (2.1). At low values of F^* , equation (2.2) predicts significantly higher values of h_o than equation (2.1) due to the action of the vapor shear forces thinning the condensate film.

Fujii et al [Ref. 12], in 1979, formed an empirical correlation for the vapor side Nusselt number from forced convection steam condensation data:

$$\frac{Nu}{Re_{26}^{1/2}} = 0.96 F^{*1/5} \quad (2.4)$$

Again, at high values of F^* , equation (2.4) gives the same result as equation (2.1).

In a situation where surface shear forces are significant for steam condensation, equation (2.4) seems to be the most accurate. The reader is referred to Rose [Ref. 13] for further reading on the topic of filmwise condensation on a smooth horizontal cylinder.

C. FILM CONDENSATION ON WIRE WRAPPED TUBES

The technique of wrapping a wire around a smooth tube to enhance performance was first introduced by Thomas [Ref. 14] in 1967 for vertical tubes. He judged that the wire, creates a low pressure region at the base of the wire due to the small

radius of curvature. This low pressure region draws in condensate from between the wires (where the pressure is greater), thinning the condensate film and improving the outside heat transfer coefficient.

The same explanation can be used to explain why enhancement occurs for a horizontal wire-wrapped horizontal tube. Figure 1 is an idealized profile of a wire wrapped tube. The low pressure region forms at the base of the wire with the higher pressure region forms between the wires. The amount of heat transferred through the wire is usually negligible compared to the rest of the surface. This is not only because of the high thermal contact resistance between the tube and the wire but also because the thicker condensate layer that is formed at the base of the wire tends to inhibit heat transfer in this region.

1. Summary of Wire-Wrap Tube Research

Previous researchers have found that wire-wrapped smooth tubes can lead to significant enhancement over plain smooth tubes. Sethumadhavan and Rao [Ref. 15] used single wire-wrapped horizontal tubes in a steam condenser with negligible vapor shear and showed that the tubes had an outside heat transfer coefficient enhancement of between 10% and 45% over plain smooth tubes; unfortunately, the material of the tube was not specified. They used three different wire diameters, 0.71 mm, 1.5 mm, and 3.0 mm. The maximum

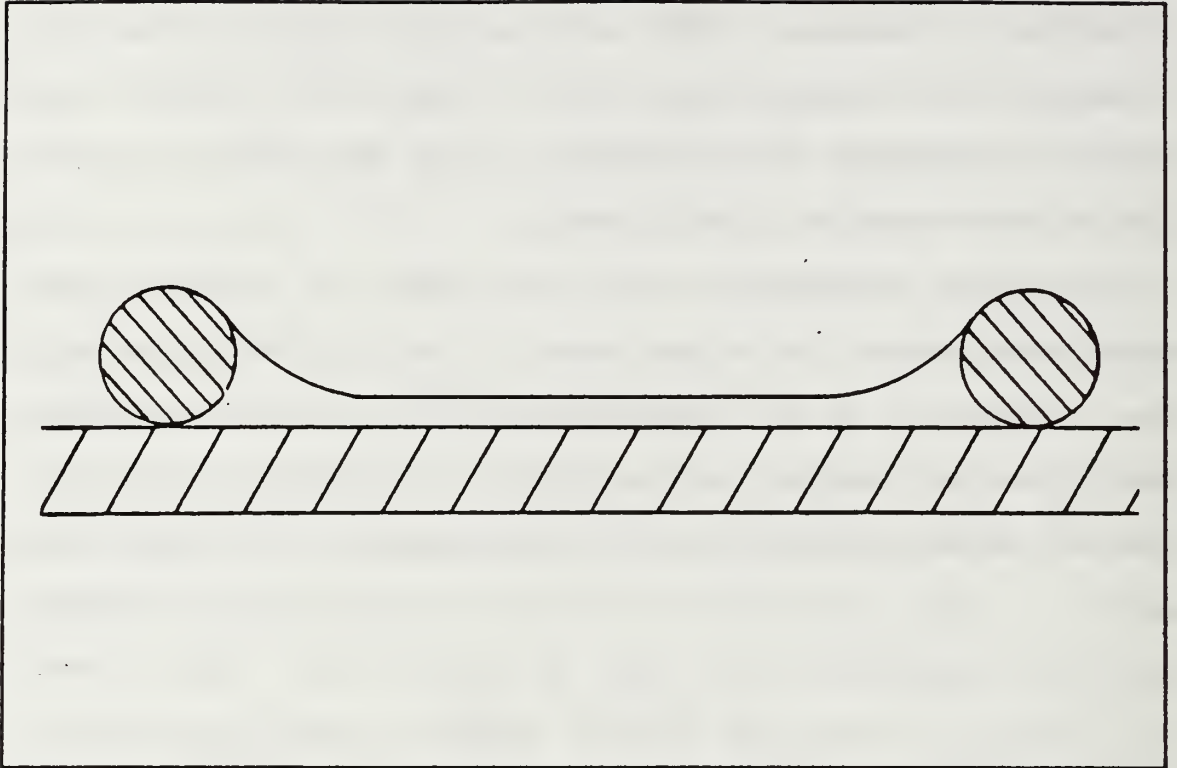


Figure 1. Idealized Condensate Film Profile on a Wire-Wrapped Tube

enhancement of 45% was obtained for the 3.0 mm wire at a pitch of 15 mm, giving a $P/D_w = 5$. The fractional coverage by the wire of the tube, F , in this case corresponded to 21%. They were trying to determine if there was a relationship between either F or P/D_w and the heat transfer enhancement such that the performance of wire-wrapped smooth tubes could be predicted.

The same year Fujii et al. [Ref. 16] presented data condensing R-11 and ethanol on a single wire-wrapped smooth tube. Wire diameters of 0.1 mm, 0.2 mm, and 0.3 mm were used on copper tubes. They showed an increase in the outside heat transfer coefficient of 2 to 3 times that predicted by the

Nusselt equation for a smooth tube. This maximum enhancement of the outside heat transfer coefficient occurred at P/D_w of 2. They also modeled the relationship between P/D_w and the outside heat transfer coefficient enhancement and found reasonable agreement with their data.

Marto et al. [Ref. 17] showed enhancements in the outside heat transfer coefficient of up to 80% for a single wire-wrapped smooth copper tube over a plain smooth copper tube condensing steam (i.e. significantly lower than that found by Fujii [Ref. 16] for R-11). Their results showed an optimum P/D_w between 5 and 7. Titanium wire diameters of 0.5 mm, 1.0 mm, and 1.6 mm were used, the difference in the results for R-11 and steam is the condensate retention between the wires for the case of steam. They then improved the model of Fujii et al. [Ref. 16] to account for the condensate retention and obtained reasonable agreement with there data.

Marto and Wanniarachchi [Ref. 19] tested smooth and roped titanium tubes, both with and without wire-wrap using steam in a tube bundle that could simulate up to 30 tubes in a vertical column. For the wire-wrapped tubes, a wire diameter of 1.6 mm was used. They reported that the mean bundle outside heat transfer coefficient could be significantly increased by using wire-wrapped tubes. Due to the fact that they are much less susceptible to the effects of condensate inundation.

D. FILM CONDENSATION ON ROPED TUBES

Roped tubes lower the overall thermal resistance in several ways; first by promoting turbulent flow on the coolant side disrupting the laminar sublayer. Secondly, the rounded geometry and grooves on the outside surface of the tube set up low pressure regions which thin the condensate film over much of the tube's outer surface area (Figure 2). The grooves in the roped tube also make it easier for the condensate to drain off the tube. By thinning the film over most of the tube surface, the outside heat-transfer is enhanced.

The disadvantage of roped tubes is that the tubeside pressure drop is increased, so more pumping capacity is needed to provide the same coolant flow rate as with a smooth tube. The magnitude of this increased pressure drop is related to the groove depth and pitch. There is therefore always a trade-off between the increased heat transfer and the increased pressure drop, which can only be sorted out from an economic standpoint.

1. Summary of Roped Tube Condensation Data

In 1971, Withers and Young [Ref. 19] evaluated the use of roped tubes in a distillation plant condenser. They obtained enhancements of up to 50% in the overall heat transfer coefficient using the roped tubes with an equal pressure drop across the coolant side of the condenser. Catchpole and Drew [Ref. 20] tested various single roped

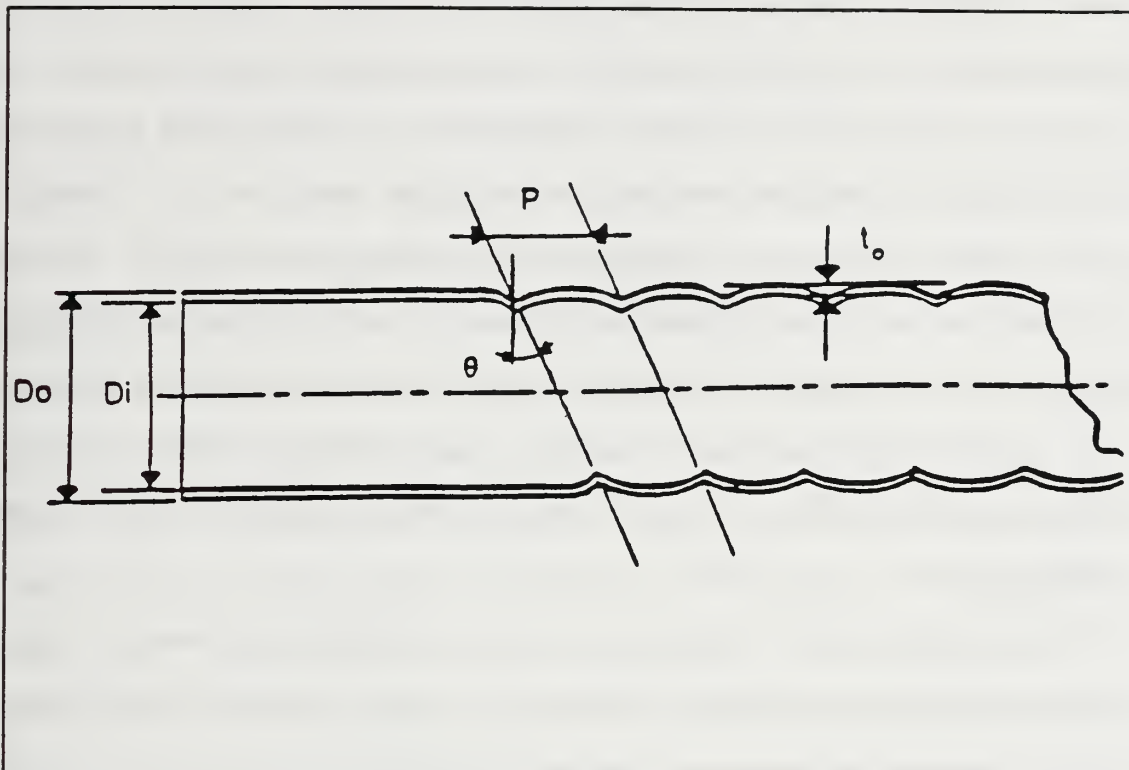


Figure 2. Profile of a Roped Tube

tubes. They varied the pitch and groove depth in the tubes and also obtained overall heat transfer improvements of up to 50%. There was always an enhancement with the roped tubes; the optimum tube for use, based on single tube data only, depended on a balance between space and weight requirements and higher operating cost due to the increased pumping power required.

Mehta and Rao [Ref. 21] tested roped aluminum tubes and were able to show that the outside heat transfer coefficient was enhanced between 16% and 38%, as compared to Nusselt theory for a smooth aluminum tube. Marto, Reilly, and Fenner [Ref. 22] tested eleven different roped tube configurations

(i.e. varying the groove pitch and depth) made of various materials. The tube was set up in a bundle arrangement to simulate a portion of a steam condenser. They found that the outside heat transfer coefficients, when compared to a smooth tube, were enhanced from 0.85 to 1.34 for the various tubes. The tubes with the highest performance had the deeper grooves and, as a consequence, larger coolantside pressure drops. They also noted that if the high performance tubes were not supported properly, there could be problems with tube vibration.

Cunningham et al. [Ref. 23, 24] studied the use of roped tube bundles in a steam condenser. They looked at two roped tubes with the same groove depth and pitch except one tube had six helical starts and the other tube had two helical starts. Their results showed that the roped tubes increased the overall heat transfer coefficient by 20% for the six start tube and up to 50% for the two start tube. The two start tubes showed higher performance for the top tube in the bundle, but lower tubes had problems with inundation. For the six start tubes, inundation did not have as large an effect as with the two start tubes, probably due to the better drainage. The six start tubes would therefore give the best overall performance when operating in a bundle.

In 1980, the Tennessee Valley authority retubed their Gallatin Steam plant Unit I condenser with 90-10 Cu-Ni LPD roped tubes and obtained an increase between 38% and 43% in

the overall bundle heat transfer coefficient, as compared to the original smooth tube bundle. However, the overall bundle heat transfer coefficient dropped as the tubes became fouled over a 2 to 4 month period. The fouling was removed by driving a stiff bristle brush through the tubes with high pressure air and water. After the fouling was removed, a 47% increase in the overall bundle heat transfer coefficient. (as compared to a smooth tube bundle) was observed [Ref. 3]. Mussalli and Gordon [Ref. 25] give a good review of the use of roped tubes in power plant condenser operations. Their paper points out that studies have shown the biofouling rate in smooth and roped tubes is approximately the same for the same water velocity. They also say that the tube enhancement may inhibit fouling buildup beyond a certain thickness due to the increased turbulence of the flow at the wall surface and that the use of chlorination treatment was effective at controlling biofouling in titanium tubes.

In summary, previous research conducted using wire-wrapped smooth and roped tubes in bundles have shown that the effects of condensate inundation can be significantly reduced. This thesis research has been conducted with a view to analyzing the enhancements in the outside heat transfer coefficient of wire-wrapped smooth and roped tubes and to determine if there is a relationship (with an optimum) between P/D_w or F to the heat transfer enhancement.

III. APPARATUS AND SYSTEM INSTRUMENTATION

A. SYSTEM OVERVIEW

The apparatus used is the same as that used by Swensen [Ref. 5]. A schematic of the overall system is shown in Figure 3. Steam is generated from distilled water using ten 4 kW, 440 Volt Watlow immersion heaters in a 0.30m diameter Pyrex boiler. The steam passes from the boiler section up through a 2.13m (ID of 0.15m) straight length of Pyrex glass piping. It is then redirected 180 degrees by two 90 degree Pyrex glass elbows, and flows 1.52m down a straight length of Pyrex tubing into the stainless steel test section. The stainless steel test section contains the horizontally mounted condenser tube as shown in Figures 3 and 4. A circular viewing port in the test section allows the condensation process to be observed during testing. Any excess steam passes through the test section and into the auxiliary condenser unit. The auxiliary condenser is constructed of a single copper coil mounted to a stainless steel base at the bottom of a Pyrex glass condenser section. The condensed water is then returned to the boiler section by a gravity drain in the baseplate of the auxiliary condenser.

The auxiliary condenser is cooled by a continuous supply of tap water controlled by a throttle valve and flow meter.

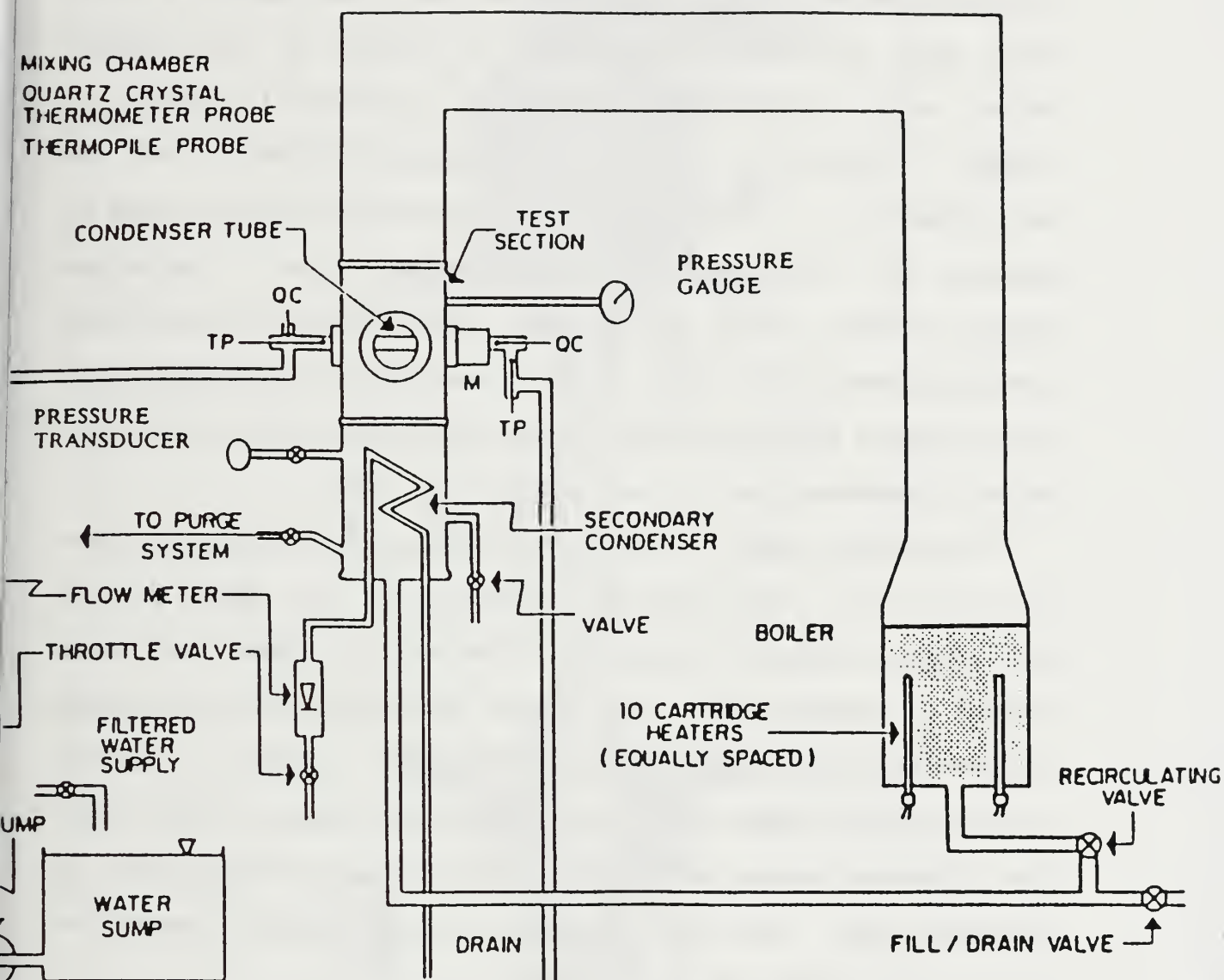


Figure 3. Schematic of the Single Tube Test Apparatus

Cooling water for the single horizontal tube is provided by a coolant system. This closed loop system consisted of a water sump tank, two centrifugal pumps in series, a flow control valve, and a calibrated flow meter as shown in Figure 3. Figure 4 shows the details of the test section and the arrangement of all the temperature measuring devices used to measure the temperature rise across the tube. The nylon mixing chamber mixes the flow at the outlet to ensure the average temperature of the flow is measured. The coolant flow rate through the horizontal tube can be varied to adjust the rate of condensation on the single test tube.

The system used to remove non-condensable gases is shown in Figure 5. The suction point is at the base of the auxiliary condenser where non-condensable gases are most likely to accumulate. The vacuum pump draws the air/steam mixture through an external condensing coil, which is located in the coolant sump tank, to condense any steam in the line. The condensed steam collects in a plexiglas container and is drained later. The air and other non-condensable gases are expelled to the atmosphere.

B. SYSTEM INSTRUMENTATION

The electrical power input to the 440 V_{ac} immersion heaters was controlled by a panel mounted potentiometer. The power calculation for the data acquisition system is described in detail by Poole [Ref. 26]. System pressure was monitored by

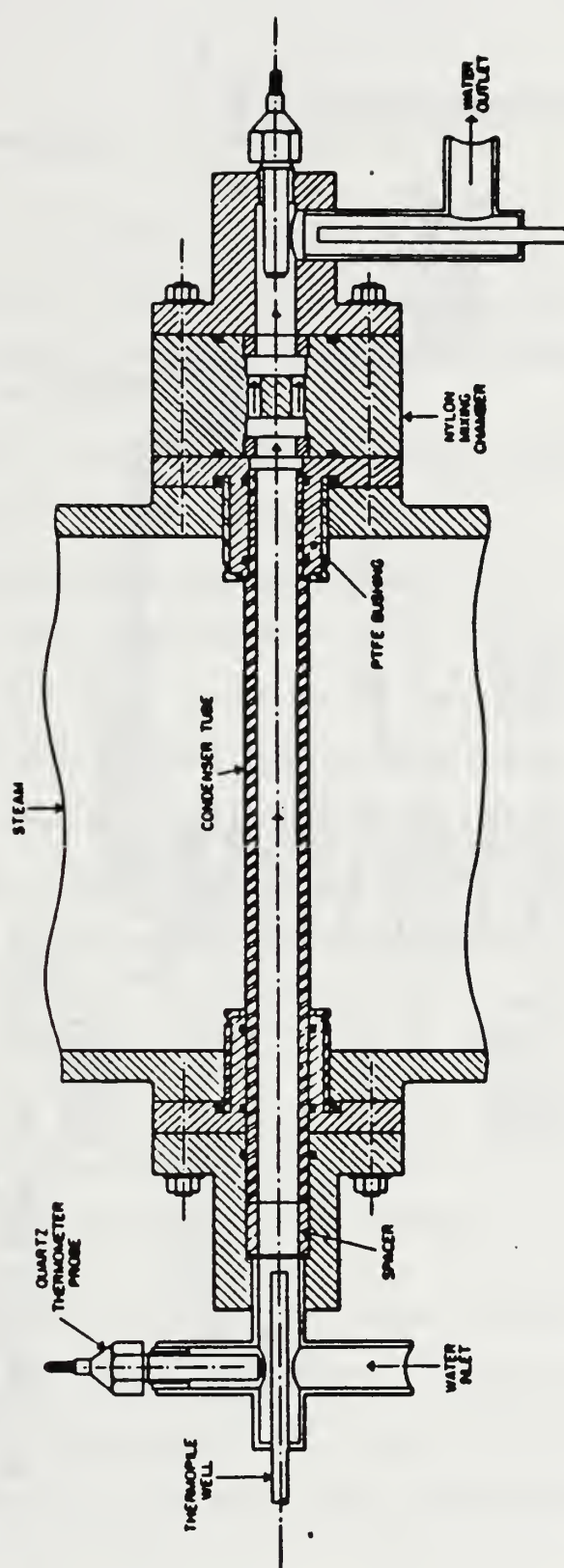


Figure 4. Schematic of the Test Section Insert

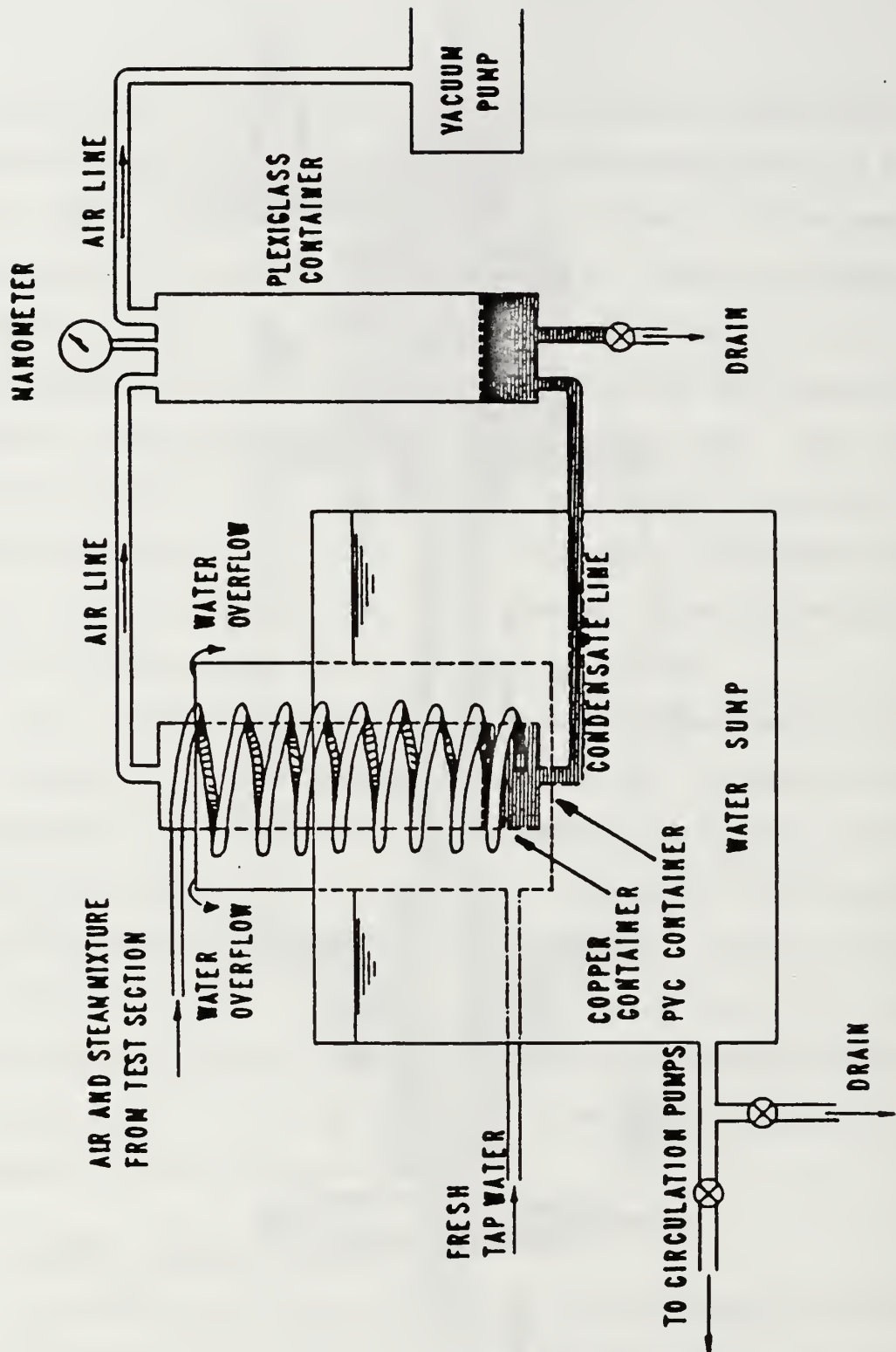


Figure 5. Schematic of Purging System and Cooling Water Sump

three different methods:

1. Setra model 204 pressure transducer.
2. System saturation temperature converted into pressure.
3. Heise solid front pressure gage (visual reading only).

The calibration for the pressure transducer and temperature instruments is given in Swensen [Ref. 5].

The system vapor temperature was measured by both a Teflon coated and a metal sheathed type-T copper/constantan thermocouple located just upstream of the test tube. The condensate return and ambient surrounding temperatures were measured with Teflon coated type-T copper/constantan thermocouples. The temperature rise of the coolant in the tube being tested was measured by three separate methods:

1. A single Teflon coated type-T copper/constantan thermocouple.
2. A ten-junction Teflon coated type-T copper/constantan thermopile.
3. An HP 2804A quartz crystal thermometer.

The relative positions of each of these three temperature measuring methods are shown in Figure 4. At the outlet of the tube, the coolant temperature is always measured after a coolant mixing chamber to ensure a well averaged temperature measurement.

All the data from the system instrumentation were processed using an HP-3497A data acquisition system controlled

by an HP-9826A computer. The raw data were processed and stored on computer disks. The data could then be reprocessed using a modified Wilson plot technique to obtain an outside heat-transfer coefficient (see section IV.C for details).

C. TUBES TESTED

There were twelve tubes fabricated for this thesis. Some of the wire-wrapped smooth tubes were the same as used by Brower [Ref. 8], except they were altered to fit into the single tube apparatus used during this thesis. Listed in Table I are all the tubes that were tested and their associated dimensions. The tubes consisted of one smooth tube and seven wire-wrapped smooth tubes, all made of titanium. Three different wire diameters were used at various spacings on the tube, providing a range of wire pitch to wire diameter between 2 and 10. These are also listed in Table I. Commercially available titanium roped tubes (Wolverine KORODENSE LPD) were also tested, both with and without the three different wire diameters. The wires were placed in the corrugated grooves, giving the wires a fixed pitch. In addition, a smooth copper tube and two of the wire-wrapped copper tubes tested by Mitrou [Ref. 9] were tested (see Table I).

Table I. LISTING OF THE TUBES TESTED

Tube No.	Tube Type	Wire Diameter (mm)	Wire Spacing (mm)	Wire Pitch (mm)	P/D Ratio	F	Outside Diameter (mm)	Inside Diameter (mm)	Tube Material
0	Smooth	None	None	None	None	0	15.85	13.86	Titanium
1	Smooth	1.6	13.47	15.07	9.42	0.108	15.85	13.86	Titanium
2	Smooth	1.6	5.75	7.35	4.59	0.205	15.85	13.86	Titanium
3	Smooth	1.6	1.80	3.40	2.13	0.457	15.85	13.86	Titanium
4	Smooth	1.0	5.04	6.04	6.04	0.158	15.85	13.86	Titanium
5	Smooth	1.0	3.70	4.70	4.70	0.211	15.85	13.86	Titanium
6	Smooth	0.5	3.46	3.96	7.92	0.120	15.85	13.86	Titanium
7	Smooth	0.5	1.51	2.01	4.02	0.218	15.85	13.86	Titanium
L	LPD	None	None	None	None	0	15.85	13.47	Titanium
L1	LPD	1.6	5.40	7.00	4.38	0.252	15.85	13.47	Titanium
L2	LPD	1.0	6.00	7.00	7.00	0.152	15.85	13.47	Titanium
L3	LPD	0.5	6.50	7.00	14.00	0.074	15.85	13.47	Titanium
50	Smooth	None	None	None	None	0	19.05	12.70	Copper
68	Smooth	1.0	3.91	3.91	3.91	0.269	19.05	12.70	Copper
71	Smooth	0.5	3.13	3.63	7.26	0.141	19.05	12.71	Copper

IV. EXPERIMENTAL PROCEDURES AND DATA REDUCTION

A. EXPERIMENTAL PROCEDURES AND OBSERVATIONS

Titanium and copper both have different wetting characteristics with respect to water. However, to ensure filmwise condensation, both types of tubes have been successfully treated with a sodium hydroxide and ethyl alcohol solution. This treatment has been used by several researchers in the past at NPS. Each tube was prepared in the following manner:

1. Both the inside and outside surfaces of the tube are cleaned using a mild soap and soft bristle brush. The tube is then rinsed first with distilled water, then with acetone, and again with distilled water to ensure there are no impurities on the surface of the tube. The second rinse should wet the entire surface of the tube with no breaks in the film. **NOTE:** the active surface area of the tube should not be handled during this procedure.
2. The tube is then placed over a steam bath.
3. Equal amounts of a 50% by weight sodium hydroxide solution and ethyl alcohol are mixed and kept warm to ensure a watery consistency is maintained.
4. The solution is then applied to the entire surface of the tube with a small brush every 10 minutes for one hour. If the tube has not been previously treated, apply the solution every 5 minutes for 20 minutes. A black oxide layer will form on the copper tubes. A layer forms on the titanium tubes, but they are not discolored.
5. The tube is then removed from the steam bath and rinsed with distilled water to remove the excess alcohol/sodium hydroxide solution. The tube should be held over the steam bath again to ensure that the entire tube surface wets easily as the steam condenses on it. The tube

should then be installed into the test section immediately afterward. Care should be taken when installing the tube into the test apparatus so the active surface of the tube is not disturbed.

The oxide layer that forms on the tube causes very good wetting characteristics on the surface of the tube. The oxide layer is very thin so it is assumed that it is negligible to the overall thermal resistance of the tube.

When the tube has been installed, the system is started up in accordance with the procedures given in Appendix B. Tests on the tubes were performed with either a HEATEX insert or no insert at all. The system is heated up to the desired operating condition, at either vacuum or atmospheric pressure, as outlined in the start-up procedure. The system needs to be maintained at equilibrium for at least thirty minutes prior to taking any data measurements. This is to ensure that the entire apparatus is warmed up. Data were taken at coolant flow rates (in %) of 80, 70, 60, 50, 40, 30, and 20, and then in steps of 10% back to 80%. Therefore, each point is checked twice at different times in the run to ensure repeatability. Several sample sets of data were evaluated to ensure the temperature difference across the tube, the saturation temperature, and the overall heat transferred were in equilibrium for each particular flow rate before the final data point was recorded. One data set took anywhere from ten to twenty minutes before the system was in equilibrium so a data set could be recorded.

Swensen [Ref. 5] describes how difficult it is to initiate filmwise condensation on a copper tube under vacuum pressure. To establish good filmwise condensation for a vacuum run, the following should be done:

1. Ensure coolant flow to the tube is secured. Then allow the apparatus vapor temperature (channel 40) to reach 3600-3800 microvolts.
2. Raise the auxiliary condenser flow rate to 50-60%, to cool the vapor temperature to ~3200 microvolts.
3. Secure the flow to the auxiliary condenser, and allow the vapor temperature to rise to 3700 - 3800 microvolts. This forms a steam blanket around the tube.
4. Initiate cooling water flow to the single tube being tested at a flow rate of at least 80%.
5. Restore flow to the auxiliary condenser to control vapor temperature and pressure. Observe the single tube through the viewing window to ensure good filmwise condensation has been established.
6. If some dropwise condensation persists, the steps above can be repeated. If dropwise condensation still continues, the tube should be removed and retreated with the ethyl alcohol and sodium hydroxide solution.

The wettability of titanium and copper are different. It was much easier to obtain filmwise condensation on the titanium tubes than the copper tubes. Also, it appeared as if it was easier to initiate filmwise condensation on the enhanced tubes than the smooth tubes. Under vacuum conditions (pressures ≈ 12 kPa) at low cooling water flow rates, small patches of dropwise condensation could be seen on the bottom of the titanium tube at fairly regular intervals. These "dryout" patches appear to be the same as those described by

Swensen [Ref. 5] for the copper tube, and are believed to be caused by vortex shedding of the vapor around the tube. When the coolant flow rate was increased above 40%, there was enough condensate to spread out and cover the tube surface and the "dryout" patches did not occur.

B. DATA REDUCTION PROCEDURES

The overall thermal resistance is represented by the sum of the coolant side resistance (R_i), the wall resistance (R_w), the fouling resistance (R_f), and the vapor side resistance (R_o). Since only clean tubes are used, the fouling resistance is negligible, ($R_f=0$). Therefore,

$$R_{total} = R_i + R_w + R_o \quad (4.1)$$

The coolant and vapor side resistances are convective in nature, so they need to be related to the areas:

$$R_i = \frac{1}{h_i A_i} \quad (4.2)$$

$$R_o = \frac{1}{h_o A_o} \quad (4.3)$$

where:

R_i = inside resistance to heat transfer (K/W)

h_i = inside heat transfer coefficient (W/m²K)

A_i = effective inside heat transfer area (m²)

R_o = outside resistance to heat transfer (K/W)

h_o = outside heat transfer coefficient (W/m²K)

A_o = effective outside heat transfer area (m^2)

The effective area for the inside of the tube is represented by the entire length of the tube. The portions of the tube that are not exposed to steam act as fins, which will remove heat in the axial direction. The extended fin assumption and the associated fin efficiencies are used to account for the inlet and outlet portions of the tube. So, the effective inside area of the tube can be represented as:

$$A_i = \pi D_i (L + L_1 \eta_1 + L_2 \eta_2) \quad (4.4)$$

where:

D_i = inside diameter of the tube (m)

L = length of tube exposed to steam, active working length (m)

L_1 = length of the inlet portion of the tube (m)

L_2 = length of the outlet portion of the tube (m)

η_1 = fin efficiency of the inlet portion of the tube

η_2 = fin efficiency of the outlet portion of the tube

The effective outside surface area is dependent on the length of the tube exposed to steam, the active condensation length. The effective outside area is represented as:

$$A_o = \pi D_o L \quad (4.5)$$

The wall resistance assumes uniform radial conduction and is represented by the following equation:

$$R_w = \frac{\ln\left(\frac{D_o}{D_i}\right)}{2\pi L k_m} \quad (4.6)$$

where:

R_w = tube wall resistance (K/W)

D_o = outside diameter of the tube (m)

D_i = inside diameter of the tube (m)

k_m = thermal conductivity of the wall material (W/mK)

The overall thermal resistance can be related to the overall heat transfer coefficient (U_o) and the effective outside area (A_o) by:

$$R_{total} = \frac{1}{U_o A_o} \quad (4.7)$$

where:

U_o = overall heat transfer coefficient (W/m²K)

Substituting equations (4.2), (4.3), and (4.7) into (4.1) gives:

$$\frac{1}{U_o A_o} = \frac{1}{h_i A_i} + R_w + \frac{1}{h_o A_o} \quad (4.8)$$

The total heat transfer rate to the single tube can be calculated from an energy balance by using the temperature difference of the cooling water across the tube and the mass flow rate of the coolant through the tube:

$$Q = \dot{m}C_p(T_2 - T_1) \quad (4.9)$$

The overall heat transfer coefficient can then be calculated from:

$$Q = U_o A_o (LMTD) \quad (4.10)$$

where:

$$LMTD = \frac{(T_2 - T_1)}{\ln \left[\frac{T_{sat} - T_1}{T_{sat} - T_2} \right]} \quad (4.11)$$

where:

- Q = total heat transfer rate (W)
- m = mass flow rate of the coolant (kg/s)
- C_p = Specific heat of coolant at constant pressure (J/kgK)
- LMTD = log mean temperature difference
- T₁ = inlet coolant temperature (K)
- T₂ = outlet coolant temperature (K)
- T_{sat} = vapor saturation temperature (K)

The inlet and outlet cooling water temperatures were measured with a quartz thermometer and the saturation temperature was measured using the vapor thermocouple (channel 40). In addition, a correction factor was used to account for the viscous heating of the coolant through the tube; there correction equations are shown in Appendix A.

Once the total heat transfer rate has been calculated, the overall heat transfer coefficient can be calculated by using equation (4.10). Now only two unknowns remain, the inside heat transfer coefficient, h_i , and the outside heat transfer coefficient, h_o . These are computed using the modified Wilson plot technique.

C. MODIFIED WILSON PLOT TECHNIQUE

The most accurate way to obtain inside and outside heat transfer coefficients is to measure the vapor temperature, mean wall temperature, and the coolant temperature directly. The coolant and vapor temperatures can be easily measured. However, to measure the tube wall temperature an, instrumented tube (with thermocouples embedded in the wall) must be used. With the instrumented tube, the inside and outside heat transfer coefficients can be calculated directly. Unfortunately, the manufacturing of instrumented tubes is costly and time consuming. Also, instrumented tubes would be impractical if a large number of tubes are to be tested.

An alternative to using an instrumented tube is to solve for both the outside and inside heat transfer coefficients simultaneously using the modified Wilson plot technique. A detailed outline of the technique is given by Marto [Ref. 27].

The modified Wilson plot technique relies on the fact that the overall heat transfer coefficient can be reliably measured from experimental data. Two forms of equations need to be

selected for the inside and outside heat transfer coefficients. In this thesis, the outside heat transfer coefficient is represented by the equation of Nusselt [Ref. 10] based on ΔT :

$$h_o = \alpha \left[\frac{k_f^3 \rho_f^2 g h_{fg}}{\mu_f D_o \Delta T_f} \right]^{1/4} = \alpha Z \quad (4.12)$$

where:

α = dimensionless Nusselt coefficient

k_f = thermal conductivity of the condensate film (W/mK)

ρ_f = density of the condensate film (kg/m³)

μ_f = dynamic viscosity of the condensate film (kg/ms)

h_{fg} = specific enthalpy of vaporization (J/kg)

ΔT_f = temperature difference across the condensate film (K)

g = gravitational constant (9.81 m/s²)

We also had the option of using Fujii's [Ref. 12] correlation, equation (2.4), for the outside heat transfer coefficient in the program used to evaluate the data. The inside heat transfer coefficient can be represented by one of several correlations. The general form for the inside heat transfer coefficient is:

$$h_i = C_i \Omega \quad (4.13)$$

where Ω varies with the particular correlation used.

Using the Sieder-Tate correlation [Ref. 6]:

$$\Omega = \frac{k_c}{D_i} Re^x Pr^{1/3} \left(\frac{\mu_c}{\mu_w} \right)^{0.14} \quad (4.14)$$

where x , the exponent to the Reynolds number, can be varied in the program evaluating the data.

Using the Sleicher-Rouse correlation [Ref. 28]:

$$\Omega = \frac{k_c}{D_i} (5 + 0.015 Re_f^c Pr_w^d) \quad (4.15)$$

where:

$$c = 0.88 - \frac{0.24}{4 + Pr_w}$$

$$d = \frac{1}{3} + 0.5 e^{-0.6 Pr_w}$$

Using the Petukhov-Popov correlation [Ref. 29]:

$$\Omega = \frac{k_c}{D_i} \left[\frac{\left(\frac{\epsilon}{8} \right) Re Pr}{K_1 + K_2 \left(\frac{\epsilon}{8} \right)^{1/2} (Pr^{2/3} - 1)} \right] \quad (4.16)$$

where:

$$\epsilon = [1.82 \log(Re) - 1.64]^{-2}$$

$$K_1 = 1 + 3.4\epsilon$$

$$K_2 = 11.7 + 1.8 Pr^{-\frac{1}{3}}$$

Substituting equations (4.12) and (4.13) into equation (4.8) gives the following:

$$\left[\frac{1}{U_o} - R_w A_o \right] Z = \frac{A_o Z}{C_i \Omega A_i} + \frac{1}{\alpha} \quad (4.17)$$

Letting:

$$Y = \left[\frac{1}{U_o} - R_w A_o \right] Z \quad (4.18)$$

and

$$X = \frac{A_o Z}{A_i \Omega} \quad (4.19)$$

a simplified linear equation results:

$$Y = mX + b \quad (4.20)$$

where

$$m = \frac{1}{C_i} \quad (4.21)$$

and

$$b = \frac{1}{\alpha} \quad (4.22)$$

the parameters Ω and Z are temperature dependent, so an iterative procedure must be used to solve the equation. A least squares fit of equation (4.17) is used to determine C_i and α . The inside heat transfer coefficient can then be determined using equation (4.13). Since h_i and U_o are both known, the outside heat transfer coefficient can be solved using equation (4.8).

It should be noted that the accuracy of the modified Wilson plot technique is dependent on the number of data points evaluated, as well as the range of flow rates used. The current computer system does not allow different run files to be combined to evaluate a tube. Each file has to be processed separately. This leads to scatter between the data runs for the values of α and C_i between runs for the same types of tube.

D. ENHANCEMENT RATIO

From Nusselt theory, it can be shown that:

$$q = a \Delta T_f^n \quad (4.23)$$

where:

$$a = \alpha \left[\frac{k_f^3 \rho_f^2 g h_{fg}}{\mu_f D_o} \right]^{1/4}$$

q = the heat flux based on the outside area (W/m^2)

ΔT_f = the temperature drop across the condensate film (K)

We also know that the heat flux can be represented by:

$$q = h_o \Delta T_f \quad (4.24)$$

So, the outside heat transfer coefficient can be represented by:

$$h_o = a \Delta T_f^{n-1} \quad (4.25)$$

From Nusselt theory, $n = 0.75$, so the enhancement ratio, based on a constant temperature drop across the condensate film, can be expressed as:

$$E_T = \frac{h_{oe}}{h_{os}} = \frac{a_e}{a_s} = \frac{\alpha_e}{\alpha_s} \quad (4.26)$$

where the subscripts of e and s refer to enhanced and smooth tubes respectively.

V. RESULTS AND DISCUSSION

A. INSIDE HEAT TRANSFER CORRELATION

Previous to this thesis, Swensen [Ref. 5] gave a discussion of how the inside heat transfer coefficient has been found at NPS. He used an instrumented tube to collect data at atmospheric pressure and empirically derived two variants of the Sieder-Tate correlation to express the inside heat transfer coefficient for a medium size copper tube ($D_i = 12.7$ mm). These correlations were represented as:

Using a HEATEX insert:

$$Nu = 0.22 Re^{0.69} Pr^{1/3} \left(\frac{\mu_c}{\mu_w} \right)^{0.14} \quad (5.1)$$

Using No insert:

$$Nu = 0.013 Re^{0.89} Pr^{1/3} \left(\frac{\mu_c}{\mu_w} \right)^{0.14} \quad (5.2)$$

Swensen developed the new correlations because it was thought that the inlet arrangement (a 90 degree bend just prior to the inlet of the tube) was affecting the correlation used to solve for the outside heat transfer coefficient. Almost all of Swensen's data were taken at atmospheric pressure using a HEATEX insert. When this thesis effort started, equations (5.1) and (5.2) were used to evaluate the inside heat transfer

coefficient. These two new correlations should provide comparable results for the outside heat transfer coefficient to those obtained by Swensen [Ref. 5]. The tubes studied in this thesis have a different inside diameter (13.86 mm) and are made from titanium and not copper.

Figures 6 and 7 show the values of the outside heat transfer coefficient for both the titanium and copper tubes at atmospheric and vacuum pressures using equations (5.1) and (5.2) in the data reduction scheme. At atmospheric pressure, Figure 6 shows Swensen's equations work well for the copper tubes; however, the results for the titanium tubes do not agree with Swensen's data well at all. In fact, a reduction of the outside heat transfer coefficient is shown for the HEATEX insert data as the temperature difference across the condensate film decreases, which is contrary to what was expected. At vacuum pressure, Swensen's equations show that the outside heat transfer coefficient curve is flatter than what is given by the instrumented copper tube data; also, the data shows much more scatter. There are several reasons this may have occurred. The first is that the leading coefficients for both correlations are fixed, so a change in the geometry (diameter) may have affected the results using these correlations. Consequently, the leading coefficient was left to 'float' to try and account for these differences. When the data were then reprocessed, the coefficient dropped by 30% for the HEATEX insert data. This drop in the leading coefficient

h_o vs. T_{cf} Atmospheric Pressure using the Swensen Correlations

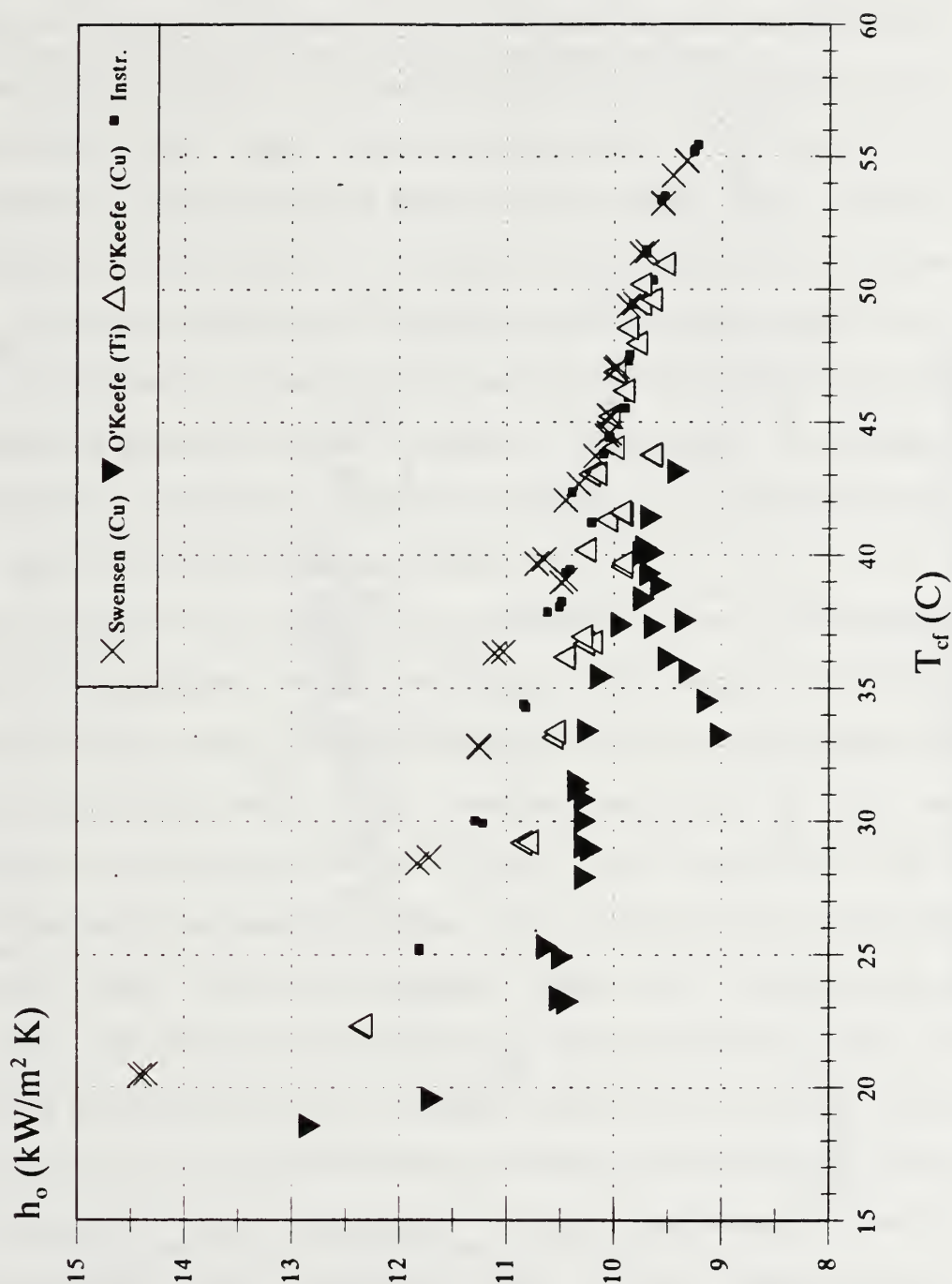


Figure 6. Comparison of Results for the Outside Heat Transfer Coefficient at Atmospheric Pressure Using the Swensen Correlations

h_o vs. T_{cf} Vacuum Pressure using the Swensen Correlations

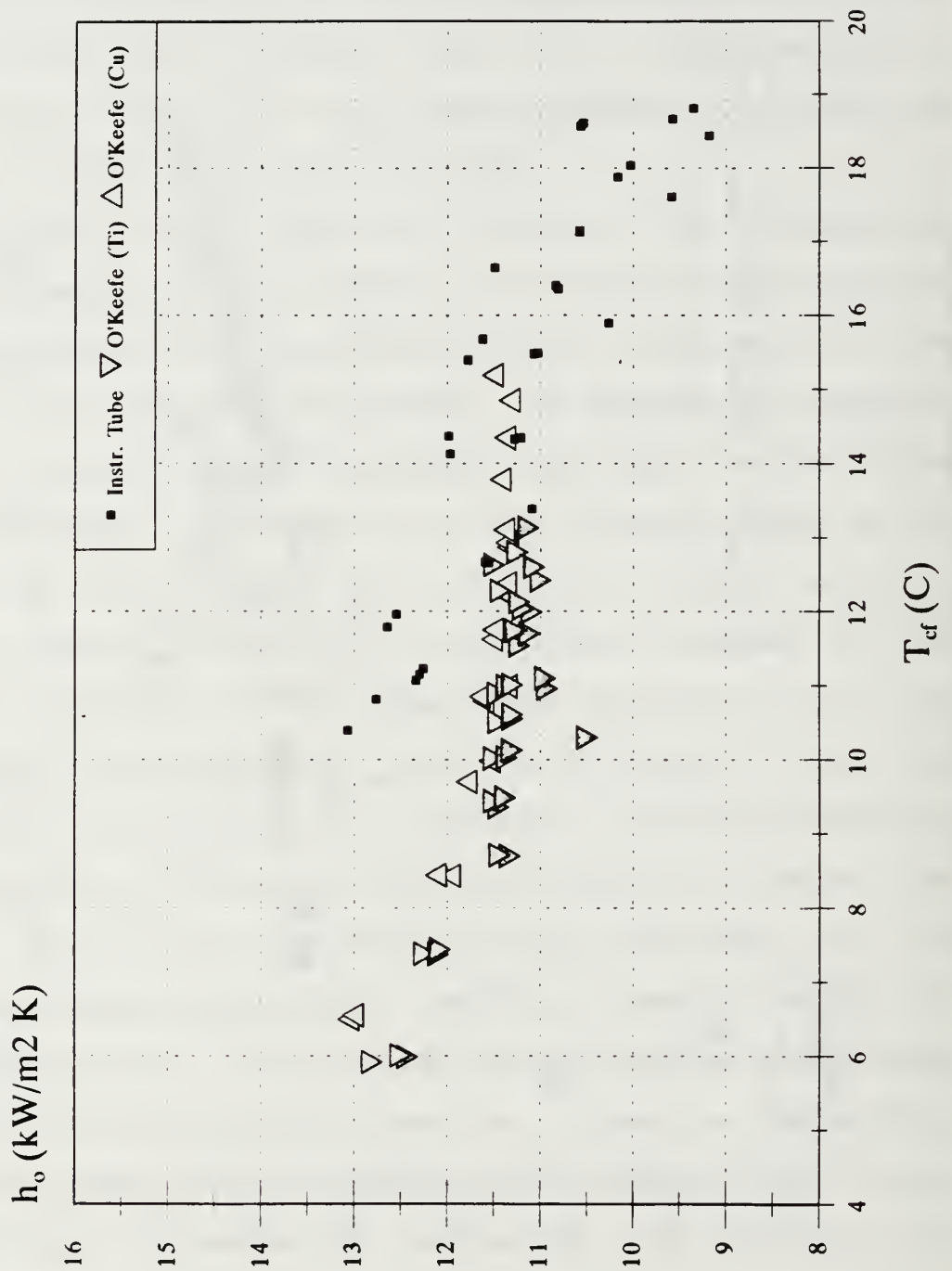


Figure 7. Comparison of the Outside Heat Transfer Coefficients at Vacuum Pressure using the Swensen Correlations

was much larger than expected, bringing into question the validity of Swensen's correlations for the titanium tube data. The other significant difference between the titanium tube data and the copper tube data is the range of ΔT_f , which is much lower for the titanium tube. The copper tube with the HEATEX insert had higher ΔT_f values for similar coolant flow rates. Swensen produced his correlations for the range of ΔT_f covered by his data. They do not seem to perform well outside this range as seen in Figures 6 and 7. Therefore, it appears as if the data reduction scheme recommended by Swensen should not be used for the titanium tubes.

In an effort to correct the problem, other inside heat transfer correlations were considered. The Argonne National Laboratory (ANL) [Ref. 31] conducted a thorough assessment of several different inside heat transfer correlations for low temperature turbulent water flows to determine which correlation was the most accurate. The conclusions of the ANL study were that the Petukhov-Popov [Ref. 30] and Sleicher-Rouse [Ref. 29] correlations were the most accurate ($\pm 5\%$) in predicting the inside heat transfer coefficient, over a range of $Pr=6.0$ to 11.6 . Both the Petukhov-Popov and Sleicher-Rouse correlations are given in Chapter IV.C and are based on having a long straight inlet section prior to the test section. Swensen identified these correlations as the most accurate but he felt that he could not use them because of the sharp bend

in the inlet flow arrangement for the test apparatus as previously mentioned.

Both Petukhov-Popov and Sleicher-Rouse correlations were then used except that a floating leading coefficient was inserted to account for the different inlet to the test section, as shown in equations (4.13), (4.15), and (4.16). Figure 8 presents the same data shown in Figure 6 for atmospheric pressure, except they have been reprocessed using the Petukhov-Popov correlation for the inside heat transfer coefficient. It can be seen that the agreement between the titanium and copper tubes is much better in this case. Furthermore, the agreement with the instrumented tube data is much better, consistently within $\pm 7\%$. Uncertainty bands are shown on this figure, and the scatter is well within the predicted uncertainty. In the same way, Figure 9 shows the same data as in Figure 7 at vacuum pressure, except the data have been reprocessed using the Petukhov-Popov correlation for the inside heat transfer coefficient. Again the results show that the titanium and copper tube data compare much better with the instrumented tube data. Again the scatter is within the uncertainty of the data. Figure 10 compares the use of the Petukhov-Popov and Sleicher-Rouse correlations and it shows similar results are obtained when the Sleicher-Rouse correlation is used in evaluating the inside heat transfer coefficient. The ANL [Ref. 31] paper said:

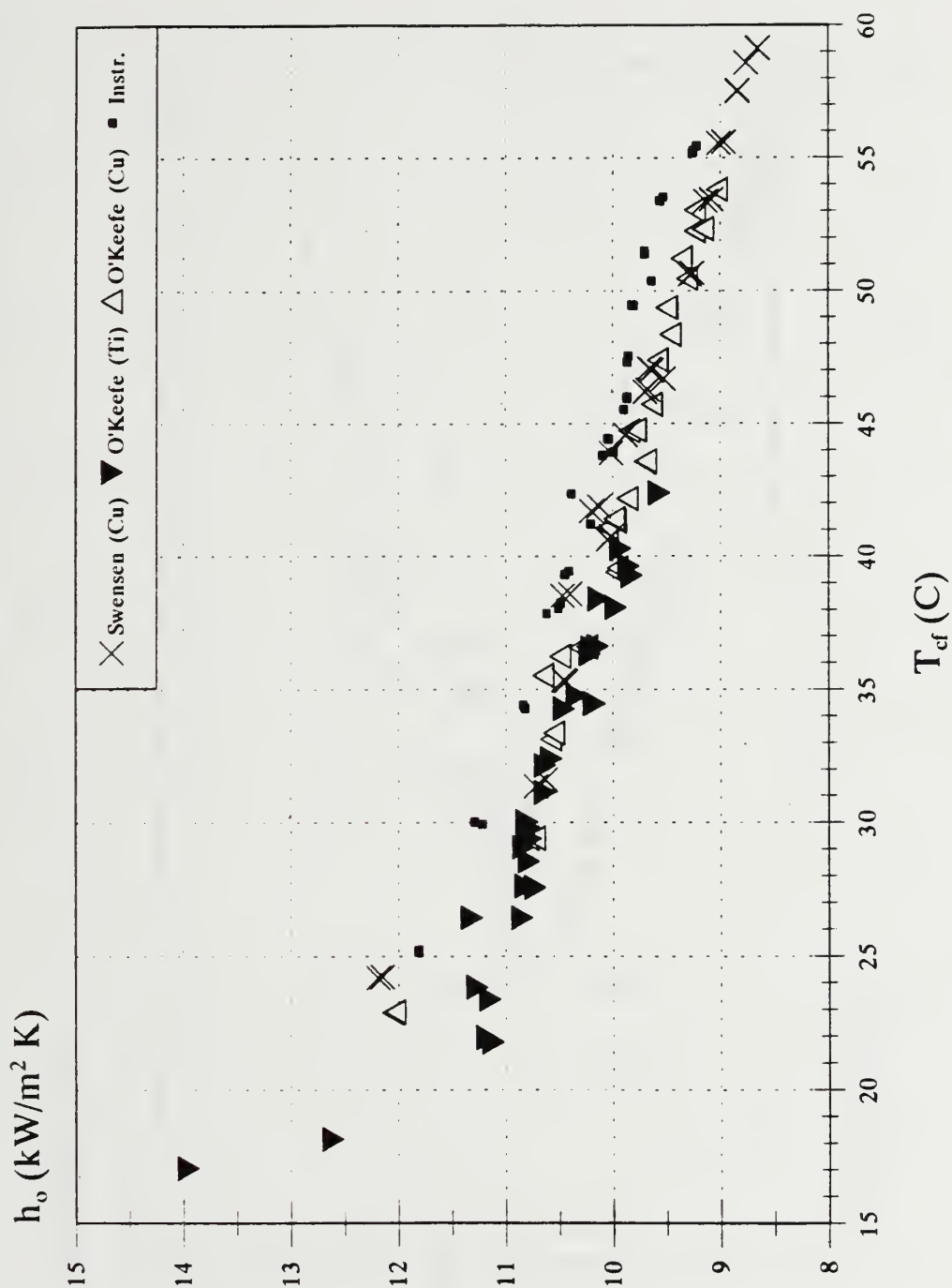


Figure 8. Comparison of the Outside Heat Transfer Coefficients at Atmospheric Pressure using the Petukhov-Popov Correlation

h_o vs. T_{cf}

Vacuum Pressure using the Petukhov-Popov Correlation

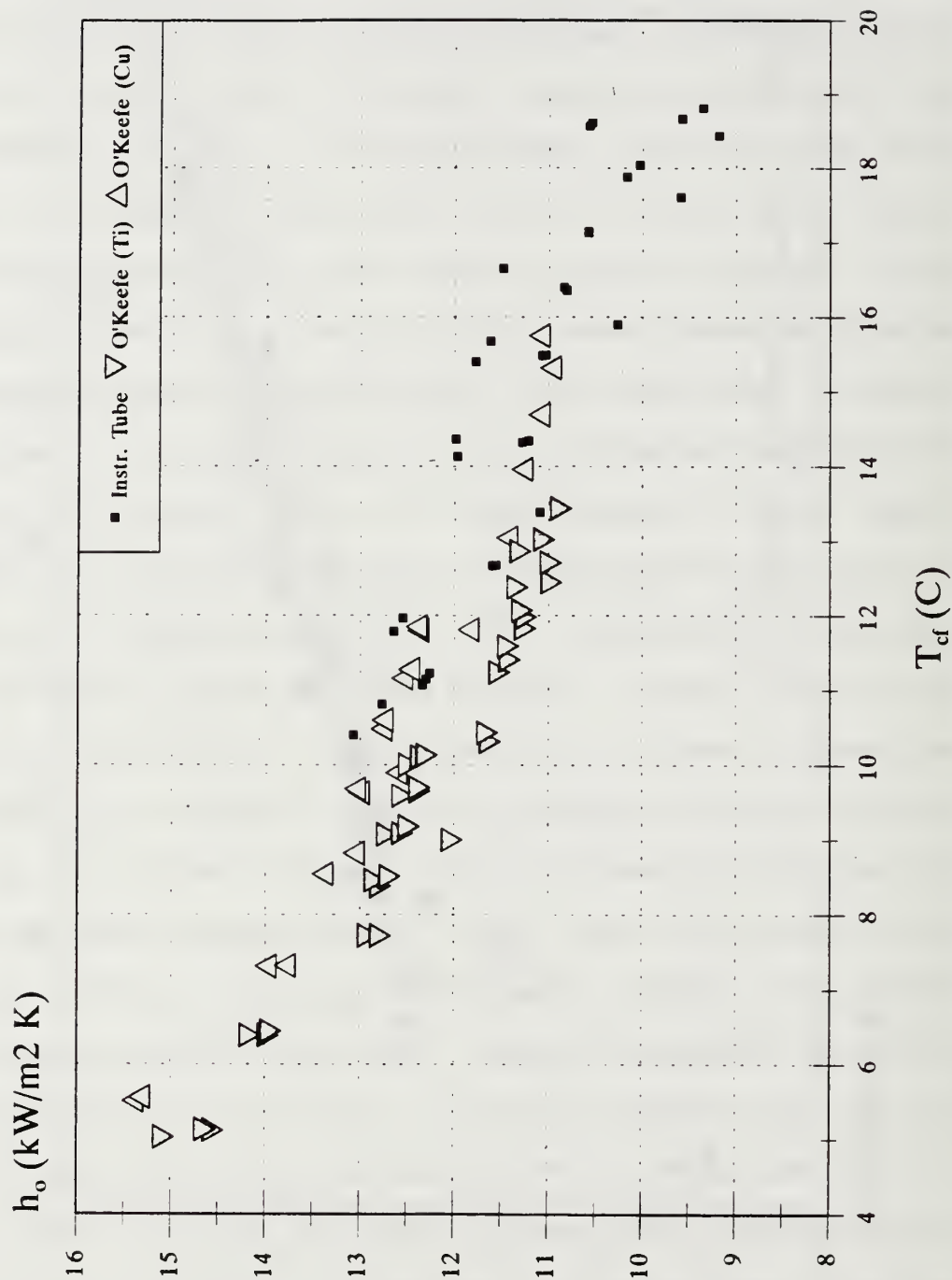


Figure 9. Comparison of the Outside Heat Transfer Coefficients at Vacuum Pressure Using the Petukhov-Popov Correlation

h_o vs. T_{cf} Atmospheric Pressure Comparison of Petukhov-Popov and Sleicher-Rouse

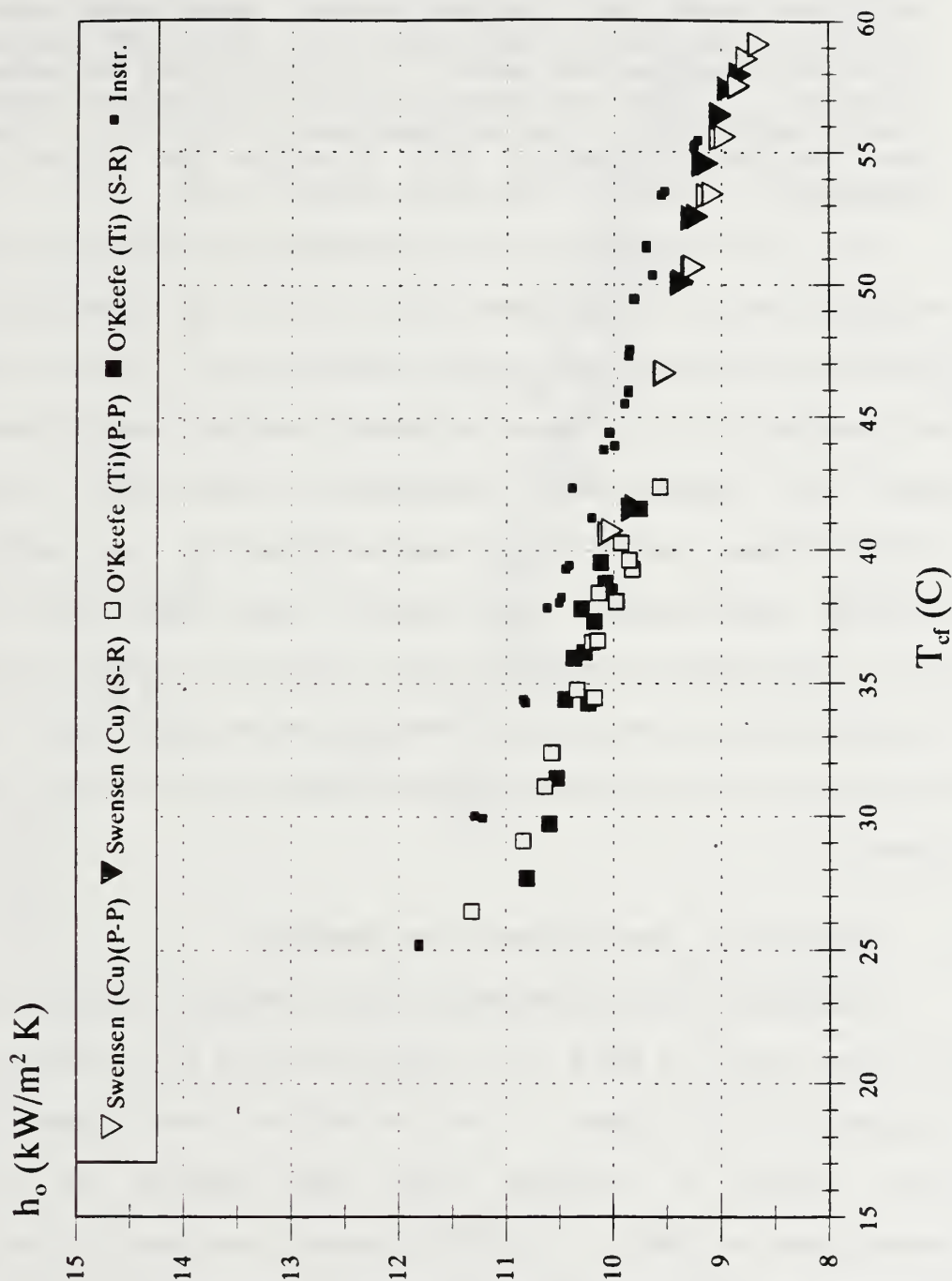


Figure 10. Comparison of the Inside Heat Transfer Coefficients using the Petukhov-Popov and Sleicher-Rouse Correlations

It is tempting to follow the "old technology" and utilize $n = 0.80$ as the Reynolds number exponent, in accordance with the popular Dittus-Boelter and Sieder-Tate correlations. However, more recent correlations, such as Petukhov-Popov and Sleicher-Rouse, have been shown to exhibit much better agreement with the most carefully obtained experimental data ... In the Pr and Re ranges of interest ... these correlations yield "effective" Reynolds number exponents in the neighborhood of $n = 0.85$. Thus it was decided to employ $n = 0.85$ in the Wilson plot procedure to generate nominal values of h_1 .

With this information, the Sieder-Tate equation was then evaluated using an exponent of 0.85 for the Reynolds number and again floating the leading coefficient. Figure 11 shows the results for the outside heat transfer coefficient when using the Sieder-Tate correlation (with $Re^{0.85}$) and the Petukhov-Popov correlation for determining the inside heat transfer coefficient. The results show that there is very little difference between using these two quite different correlations for the inside heat transfer coefficient, giving confidence in the data reduction technique for the titanium tubes.

B. ANALYSIS OF THE SMOOTH TUBE RESULTS

A series of runs were made using a smooth titanium tube to get some baseline data for comparison with the enhanced wire-wrapped titanium tubes. A smooth medium sized copper tube was also tested to compare with the results of previous researchers at NPS. A HEATEX insert was used to boost the values of the inside heat transfer coefficient and thereby improve the measured accuracy of the outside heat transfer

h_o vs. T_{cf} Atmospheric Pressure Comparison of Petukhov-Popov and Sieder Tate ($Re^{.85}$)

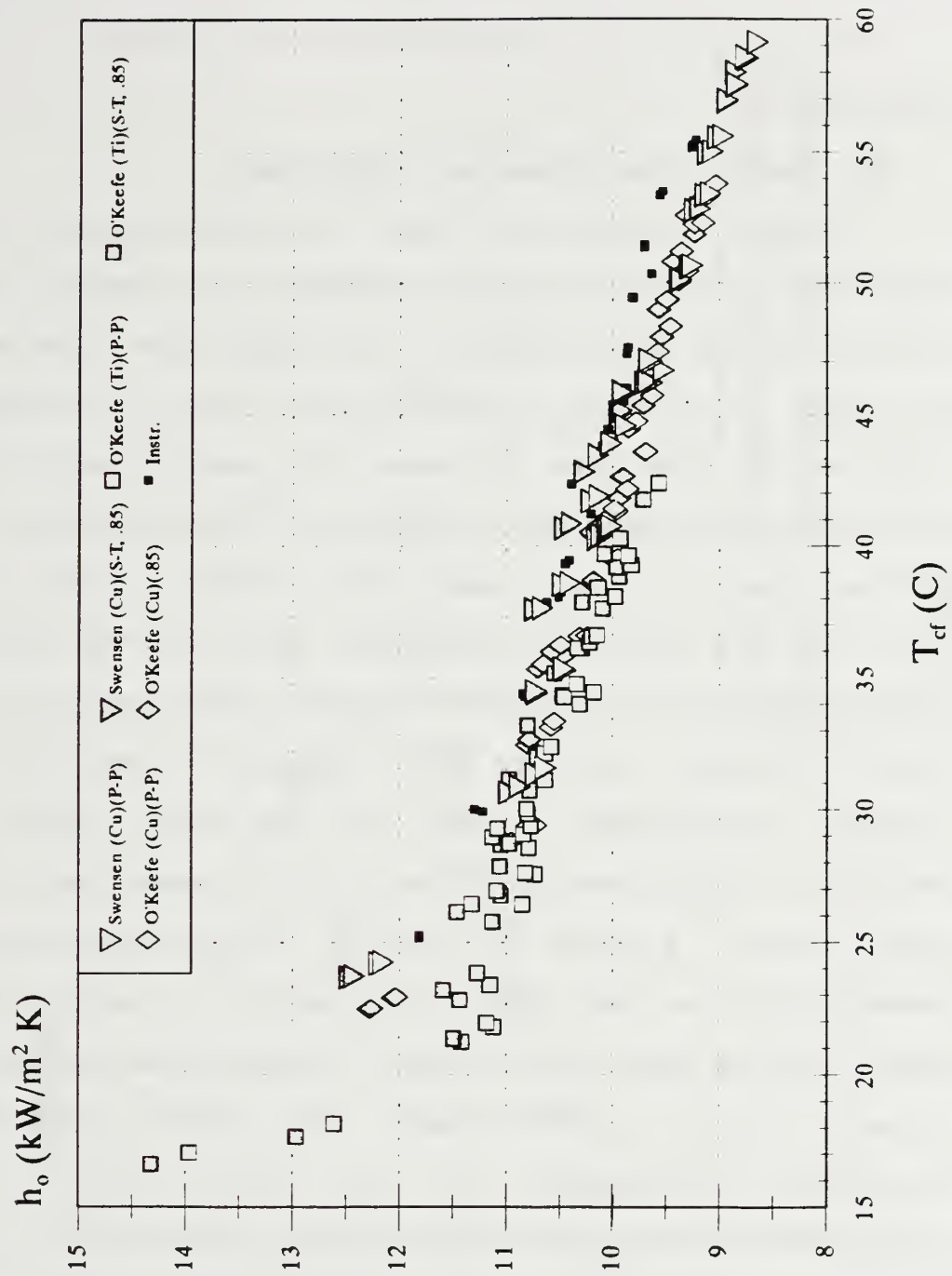


Figure 11. Comparison of the Outside Heat Transfer Coefficients for Atmospheric Pressure Using the Petukhov-Popov and Sieder-Tate ($Re^{.85}$) Correlations

coefficient.

1. Overall Heat Transfer Coefficient

Figures 12 through 15 show the overall heat transfer coefficient values for each atmospheric and vacuum pressure run done on the smooth titanium and copper tube. The shape of the curve is related to the coolant flow rate through the tube; as the flow rate increases the overall heat transfer coefficient increases due to improved coolant mixing. It is obvious that in every case, the overall heat transfer coefficient is higher for the copper tube ($\approx 18\%$ for the HEATEX insert data and $\approx 14\%$ for the no insert data at a coolant flow rate of 2.5 m/s). Most of this increase in the overall heat transfer coefficient is due to the much smaller wall resistance (approximately a factor of 6) associated with the copper tube. Figures 12 through 15 also show excellent repeatability of the data. The effect of using a Heatex insert can be seen in Figure 16, which shows values of U_o averaged for all the data taken. The HEATEX insert gives a significant enhancement in the overall heat transfer coefficient of around 20% for a coolant flow rate of 2.25 m/s. The vapor shear forces also effect the overall heat transfer coefficient (U_o). It can be seen that U_o is higher for the vacuum runs ($U_o \approx 2$ m/s) than the atmospheric runs ($U_o \approx 1$ m/s) because of the higher vapor shear effect. However, this vapor shear effect is small ($\leq 5\%$) when compared to the effect that

U_o vs. V_w Smooth Tube at Atmospheric Pressure with a HEATEX Insert

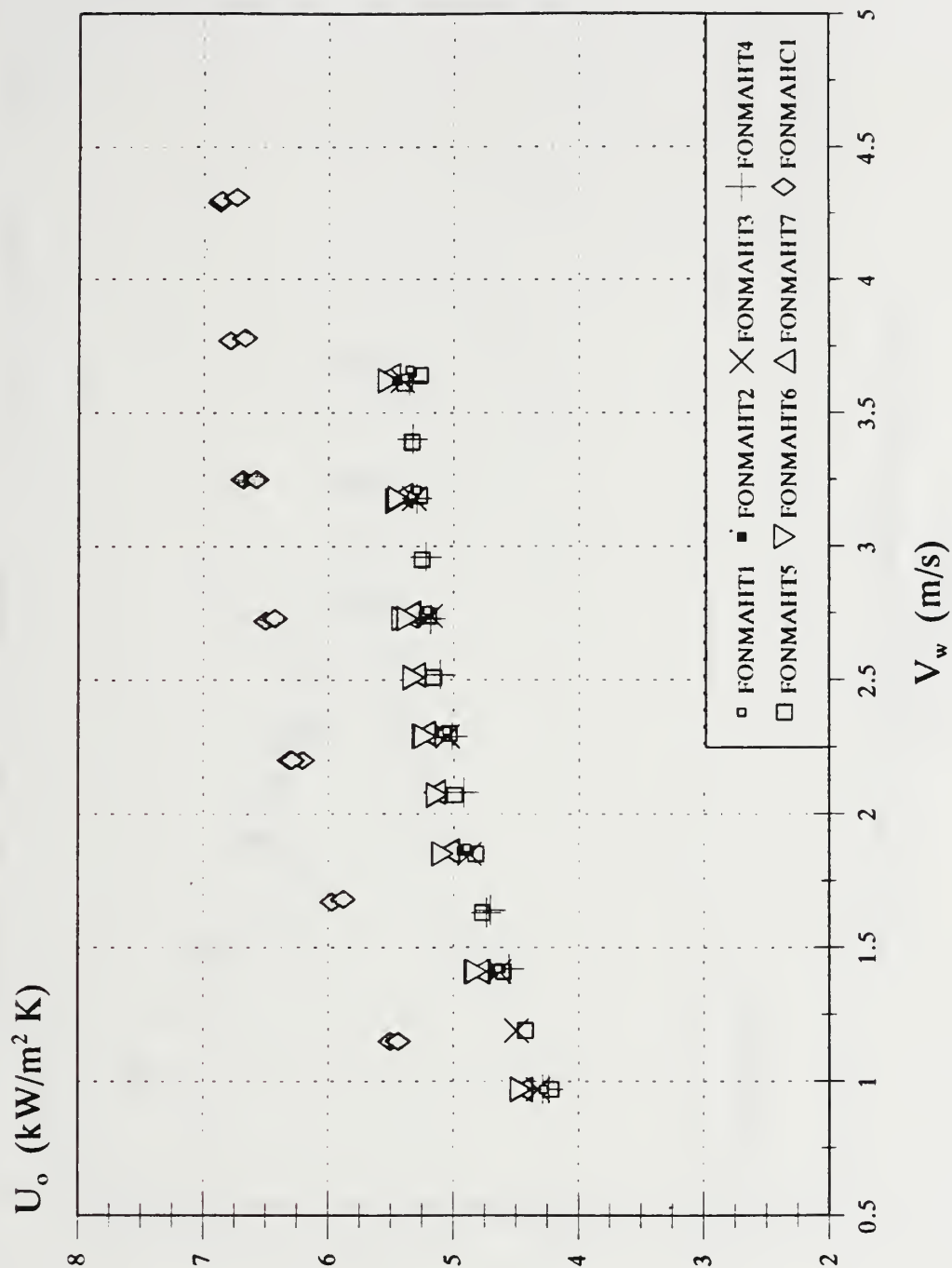


Figure 12. U_o vs. V_w for a Smooth Tube at Atmospheric Pressure with a HEATEX Insert

U_o vs. V_w Smooth Tube at Atmospheric Pressure with No Insert

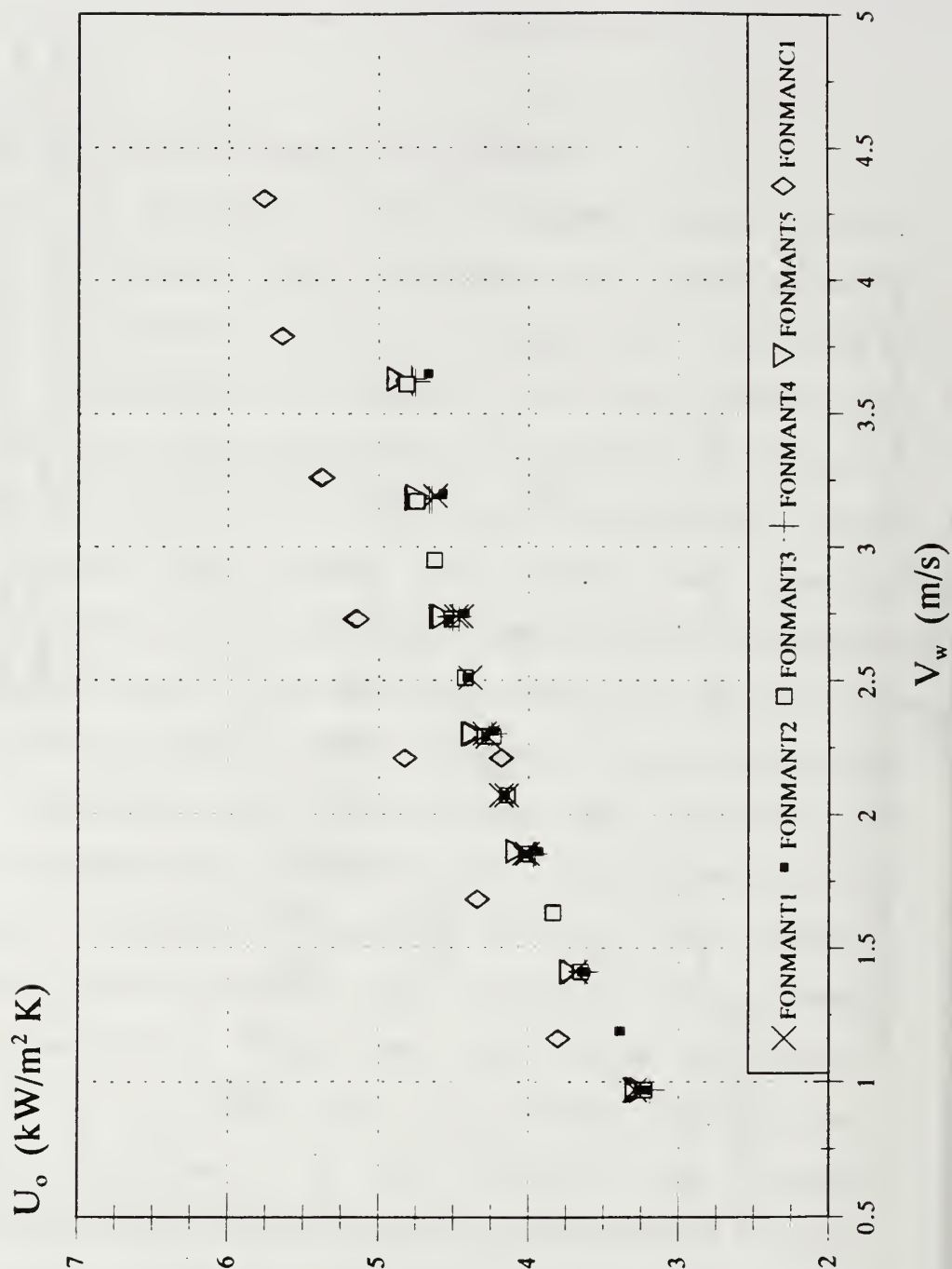


Figure 13. U_o vs. V_w for a Smooth at Atmospheric Pressure with No Insert

U_o vs. V_w Smooth Tube at Vacuum Pressure with a HEATEX Insert

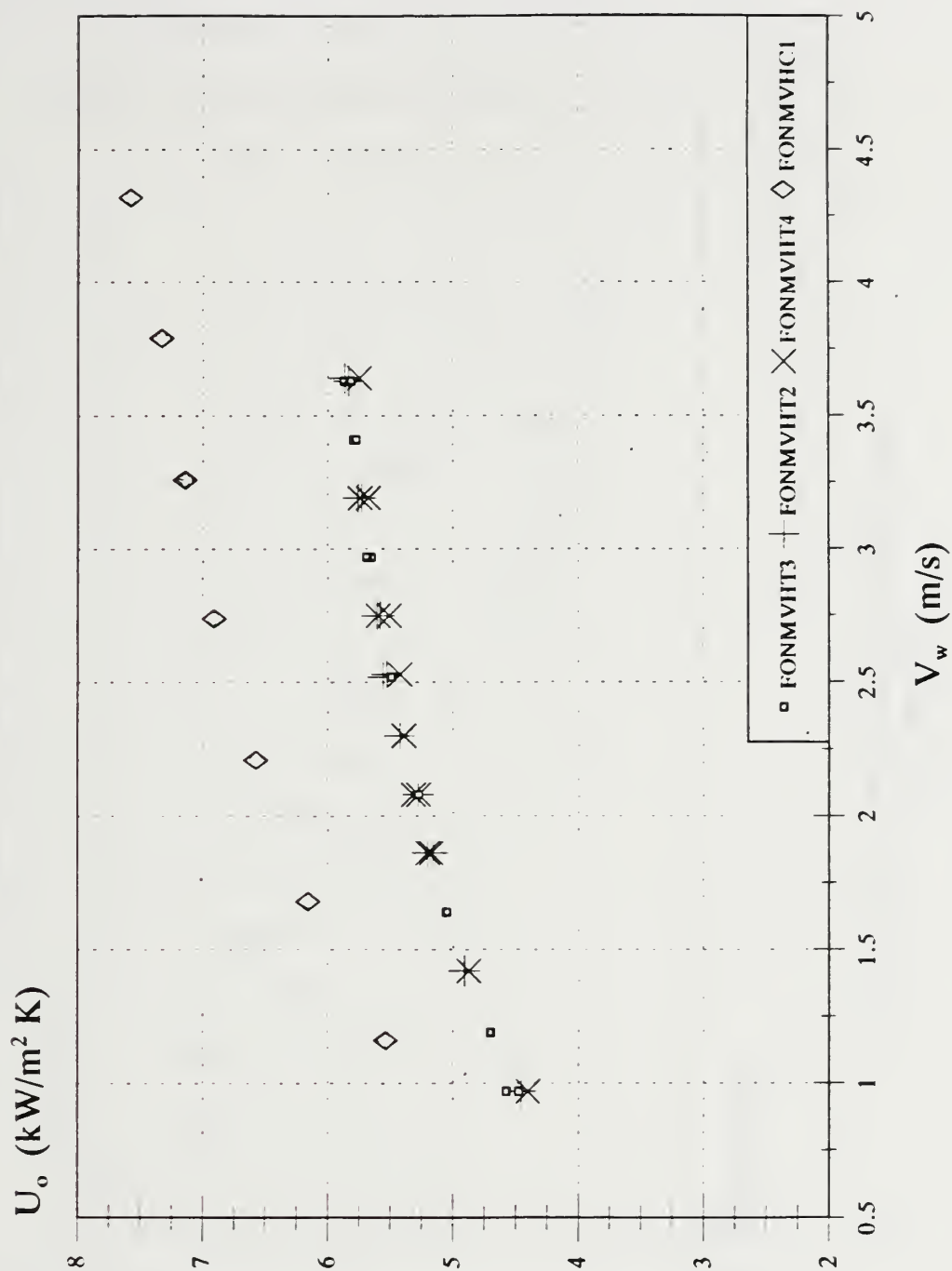


Figure 14. U_o vs. V_w for a Smooth Tube at Vacuum Pressure with a HEATEX Insert

U_o vs. V_w Smooth Tube at Vacuum Pressure with No Insert

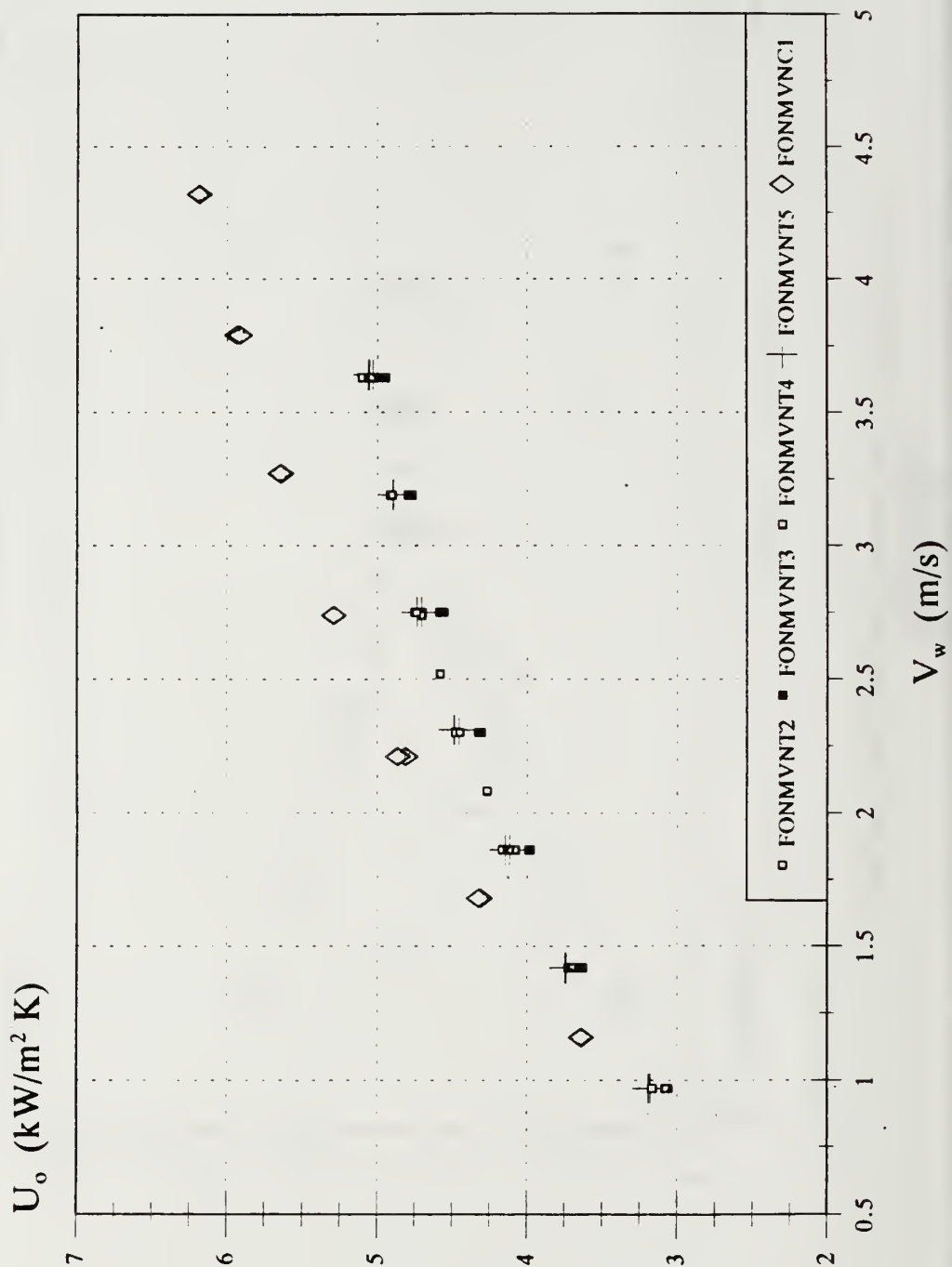


Figure 15. U_o vs. V_w for a Smooth Tube at Vacuum Pressure with No Insert

U_o vs. V_w Smooth Titanium Tube Average U_o Values

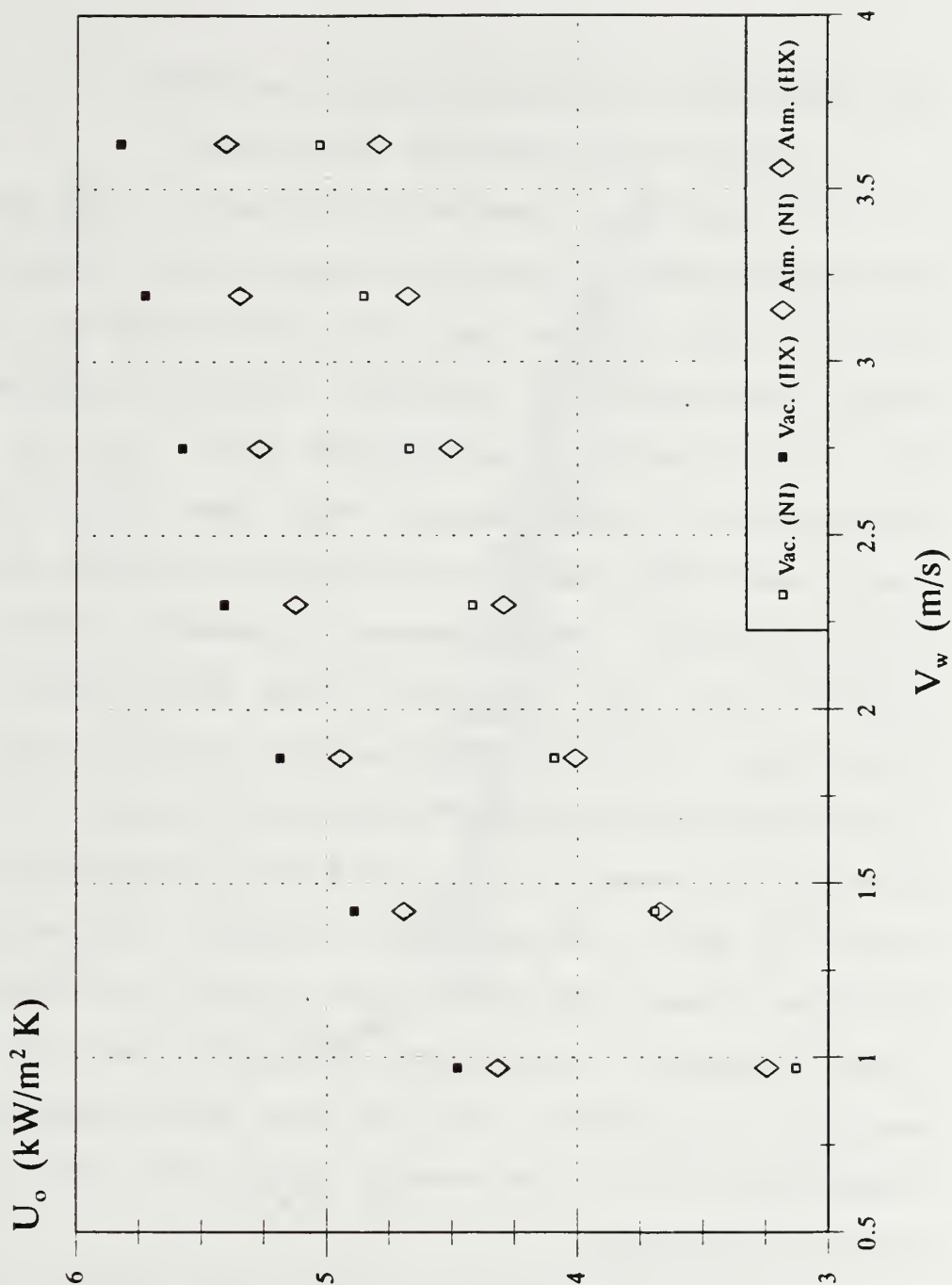


Figure 16. Effect of Vapor Velocity on Smooth Titanium Tubes Average U_o Values

the insert has at the same coolant velocity.

2. Outside Heat Transfer Coefficient

The outside heat transfer coefficient is determined using the Nusselt [Ref. 10] equation based on ΔT_f , equation (4.12). Figures 17 and 18 show the outside heat transfer coefficient versus the temperature difference across the condensate film for all the smooth titanium tube data. Several previous researcher's smooth copper tube data have also been reprocessed using the Petukhov-Popov correlation and plotted in the figures. For atmospheric pressure, there is good agreement for all the copper tube data between all the researchers. The titanium tube data, however, tends to fall below the copper tube data, agreeing more closely with Nusselt theory. The reason for the two Nusselt theory lines in each figure is due to the different diameters for the copper and titanium tubes. The vacuum data (Figure 17) shows the same lower values for the titanium tube. The reason for the large scatter is probably due to the much smaller coolant temperature rise in the case of the titanium tube, making the data less accurate.

In order to compare the outside heat transfer coefficient of the smooth tube to each of the enhanced tubes, the Nusselt coefficient, α , needs to be determined under similar conditions for each tube. A summary of the results for the data reduction analysis for the leading coefficients (C_1)

h_o VS. T_{cf} Atmospheric Pressure

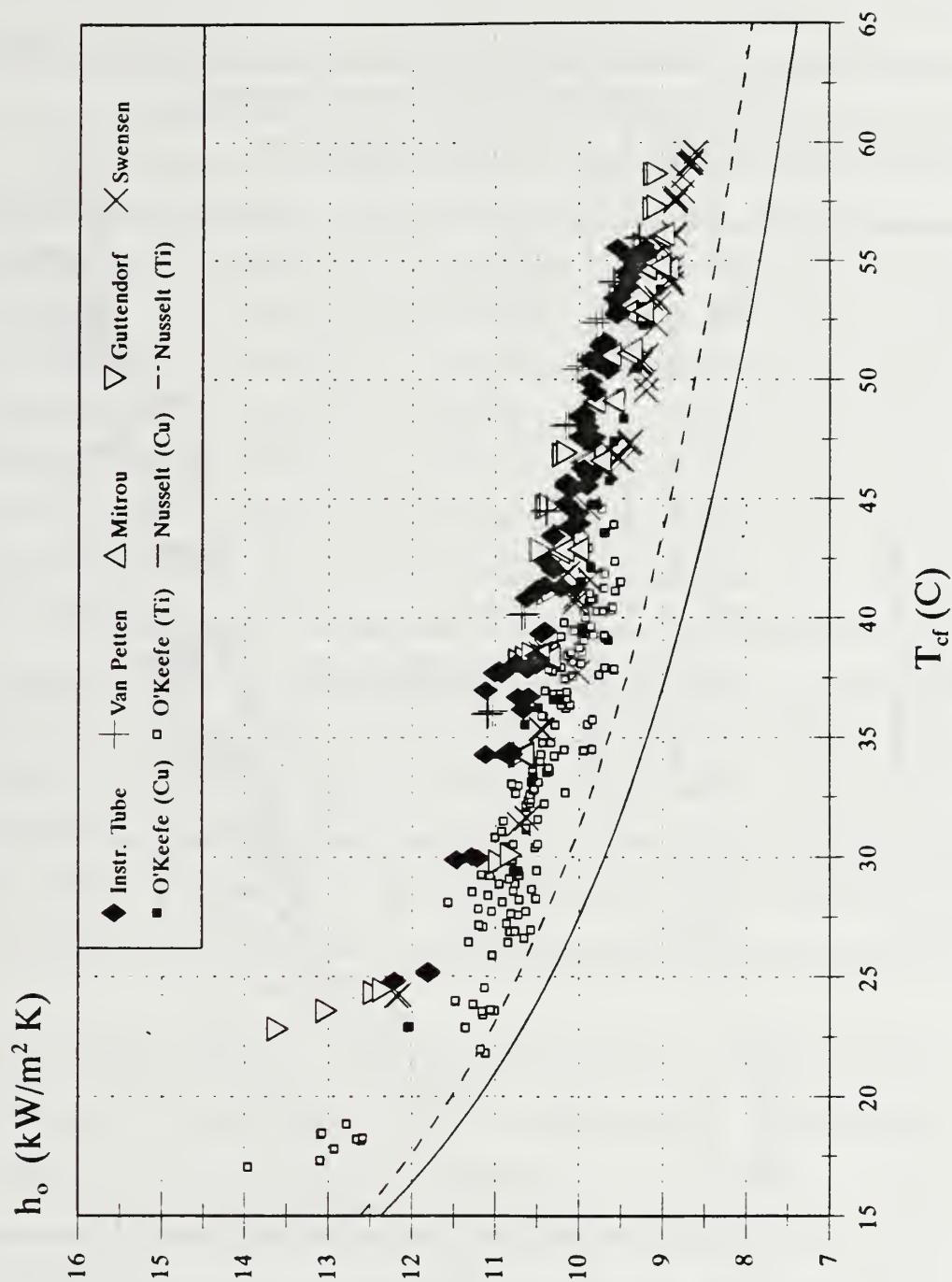


Figure 17. h_o vs. ΔT_r for Smooth Tubes at Atmospheric Pressure

h_o vs. T_{cf} Vacuum Pressure

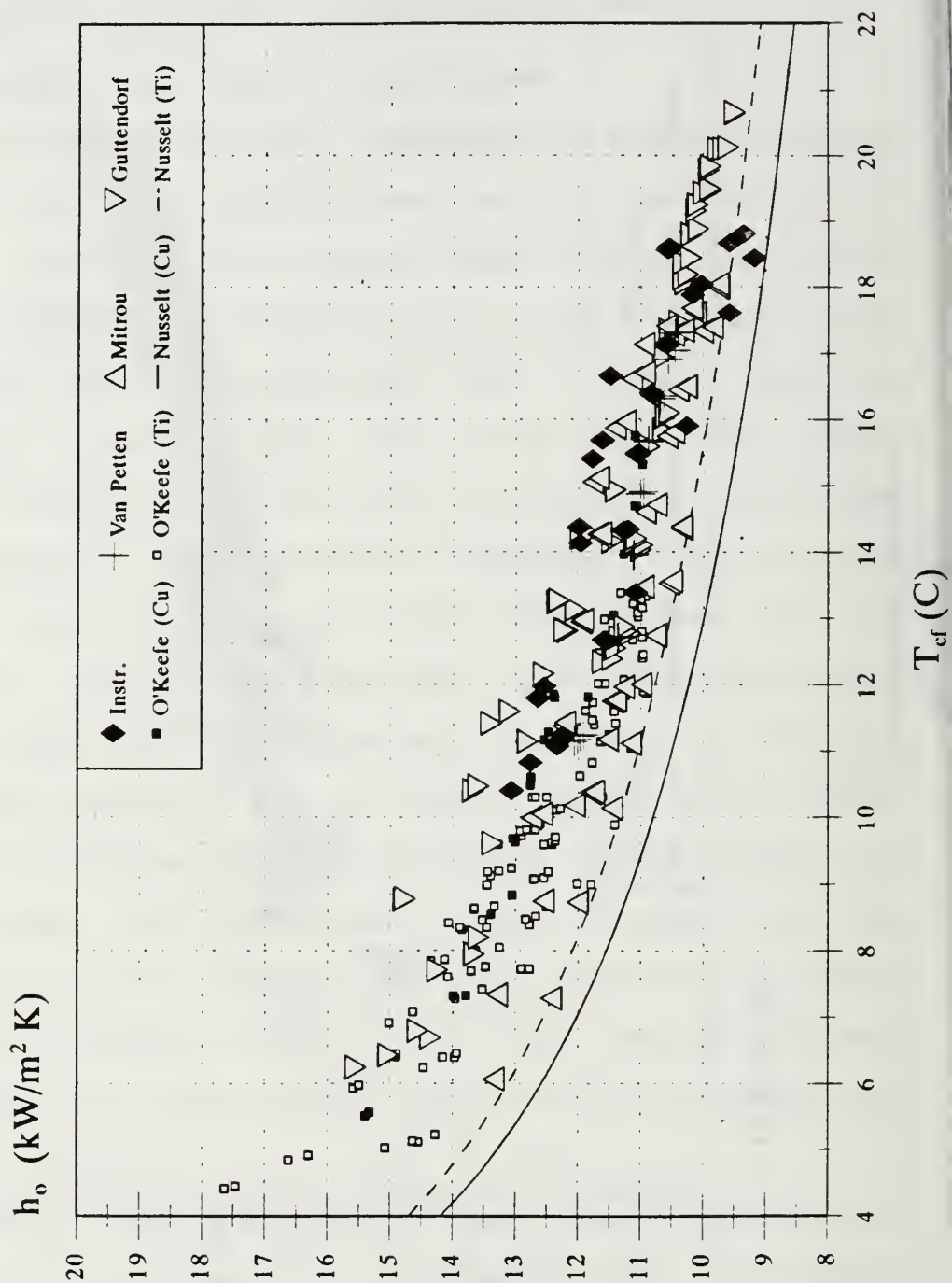


Figure 18. h_o vs. ΔT_r for a Smooth Tube at Vacuum Pressure

Table II. SMOOTH TITANIUM TUBE WITH A HEATEX INSERT (PRESENT WORK)

Atmospheric Pressure HEATEX Insert				
	Petukhov-Popov		Sieder-Tate ($Re^{.85}$)	
Data Run	C_1	α	C_1	α
FONMAHT1	2.372	0.780	0.038	0.787
FONMAHT2	2.383	0.774	0.038	0.780
FONMAHT3	2.392	0.755	0.038	0.761
FONMAHT4	2.410	0.748	0.038	0.753
FONMAHT5	2.201	0.770	0.035	0.777
FONMAHT6	2.541	0.776	0.040	0.781
FONMAHT7	2.511	0.793	0.040	0.799
Atm. Avg.	2.401	0.776	0.038	0.777
Vacuum Pressure HEATEX Insert				
FONMVHT3	2.547	0.748	0.043	0.748
FONMVHT4	2.278	0.790	0.038	0.791
FONMVHT5	2.422	0.763	0.041	0.763
Vac. Avg.	2.416	0.767	0.041	0.767
Total Avgs.	2.406	0.770	0.039	0.774

using the Petukhov-Popov and Sieder-Tate ($Re^{.85}$) correlations, and the Nusselt coefficients (α) for the smooth titanium and copper tubes are presented in Tables II through VI. The printouts for all the data runs are given in Appendix D. The researcher initials are as follows: (G)=Guttendorf [Ref. 32], (M)=Mitrou [Ref. 9], (O)=O'Keefe, (S)=Swensen [Ref. 5], and (V)= Van Petten [Ref. 4].

When using the modified Wilson plot technique to reprocess the data, the leading coefficient for the inside heat transfer

Table III. SMOOTH TITANIUM TUBE WITH NO INSERT (PRESENT WORK)

Atmospheric Pressure No Insert				
	Petukhov-Popov		Sieder-Tate ($Re^{.85}$)	
Data Run	C_1	α	C_1	α
FONMANT1	1.211	0.750	0.019	0.765
FONMANT2	1.185	0.760	0.018	0.776
FONMANT3	1.169	0.765	0.018	0.777
FONMANT4	1.181	0.765	0.018	0.778
FONMANT5	1.237	0.786	0.019	0.801
Avg.	1.197	0.765	0.018	0.779
Vacuum Pressure No Insert				
FONMVNT2	1.092	0.822	0.018	0.822
FONMVNT3	1.078	0.788	0.018	0.789
FONMVNT4	1.075	0.846	0.018	0.847
FONMVNT5	1.113	0.827	0.019	0.829
NI Avg.	1.089	0.821	0.018	0.822
Total Avg.	1.149	0.790	0.018	0.798

correlation can either be set with a user supplied value or left to "float", allowing the program to solve for the 'best' value of the coefficient itself as described in Chapter 4. Theoretically, if the leading coefficient is allowed to float, the coefficient should be about the same for all tubes with the same inner diameter. The tables show that the HEATEX inert enhances the inside heat transfer coefficient by a factor of around 2.5. Swensen [Ref. 5] and Micheal et al. [Ref. 33], show that as the vapor velocity across the tube

increases, the value of α increases because of the thinning of the film caused by the vapor shear. In Tables II through VI there is a general trend that the value of α increases between atmospheric ($U_{\infty} \approx 1.0$ m/s) and vacuum ($U_{\infty} \approx 2.0$ m/s) runs.

Table IV. SMOOTH COPPER TUBE WITH A HEATEX INSERT

Atmospheric Pressure HEATEX Insert				
	Petukhov-Popov		Sieder-Tate ($Re^{.85}$)	
Data Run/Researcher	C_1	α	C_1	α
FONMAHC1 (O)	2.809	0.832	0.044	0.835
FNMAVSH4 (S)	3.187	0.819	0.051	0.823
FNMAVSH8 (S)	3.083	0.824	0.049	0.830
FSOMASH3 (S)	3.031	0.818	0.048	0.826
Atm. Avgs.	3.028	0.823	0.048	0.828
Vacuum Pressure HEATEX Insert				
FONMVHC1 (O)	2.482	0.838	0.042	0.838
Total Avgs.	2.918	0.826	0.047	0.830

When the titanium tube is compared to the copper tube, the value of α for the titanium tube is significantly less than the α for the copper tube at the same vapor velocity. The value of α could be affected (between titanium and copper) by the difference in temperature profiles at the surface of the tube caused by the different material thermal conductivities. The copper tube will exhibit a much more uniform temperature profile around the tube than the titanium tube. This will affect the properties of the condensate film covering the

Table V. SMOOTH COPPER TUBE WITH A WIRE WRAP INSERT

Atmospheric Pressure Wire Wrap Insert				
	Petukhov-Popov		Sieder-Tate (Re	
Data Run/Researcher	C_1	α	C_1	α
SMTHSTA654 (V)	2.653	0.875	0.042	0.8
S001S1A3 (G)	2.722	0.855	0.043	0.8
S50A213 (M)	2.335	0.850	0.036	0.8
S50A220 (M)	2.272	0.834	0.035	0.8
Atm. Avgs.	2.495	0.853	0.039	0.8
Vacuum Pressure Wire Wrap Insert				
M1STV103 (V)	2.607	0.827	0.044	0.8
S001S1V3 (G)	2.538	0.818	0.043	0.8
S001S1V4 (G)	2.575	0.823	0.043	0.8
S001S1V5 (G)	2.644	0.815	0.044	0.8
S50V181 (M)	2.102	0.856	0.035	0.8
S50V184 (M)	2.142	0.802	0.036	0.8
Vac. Avgs.	2.435	0.823	0.041	0.8
Total Avgs.	2.459	0.835	0.040	0.8

tube, which in turn affect the values of α . Another reason could be the fact that it was much easier to get filmwise condensation on the titanium than on the copper tube, presumably because of the different surface wettability characteristics of titanium and copper with water. This could lead to differences in the condensate film and even some dropwise condensation in the case of the copper tube.

Table VI. SMOOTH COPPER TUBE WITH NO INSERT

Atmospheric Pressure No Insert				
	Petukhov-Popov		Sieder-Tate ($Re^{.85}$)	
Data Run/Researcher	C_1	α	C_1	α
FONMANC1 (O)	1.265	0.816	0.019	0.828
FSONMASN1 (S)	1.355	0.833	0.021	0.847
S001S0A2 (G)	1.347	0.858	0.021	0.875
Atm. Avgs.	1.322	0.836	0.020	0.850
Vacuum Pressure No Insert				
FONMVNC1 (O)	1.085	0.866	0.018	0.867
S001S0V2 (G)	1.056	0.904	0.017	0.909
S001S0V3 (G)	1.147	0.872	0.019	0.876
S50V177 (M)	0.970	0.774	0.016	0.858
Vac. Avgs.	1.064	0.854	0.018	0.857
Total Avgs.	1.175	0.846	0.019	0.841

C. ANALYSIS OF THE WIRE-WRAPPED SMOOTH TUBES

The seven wire-wrapped titanium smooth tubes fabricated for this thesis and two of the wire-wrapped copper tubes used by Mitrou [Ref. 9] were tested under vacuum and atmospheric conditions to find the enhancement compared to a smooth tube for a constant temperature drop across the condensate film. Previous research done in this area has tried to find the optimum relationship between this enhancement and the wire pitch, wire diameter, and the fraction of tube covered by wire.

The overall heat transfer coefficients are similar to the smooth tube curves except that any enhancement due to the wire

can be seen directly on this curve. The same effects caused by the insert and vapor shear (as mentioned previously) also apply to the wire-wrapped tubes. Figure 19 shows the overall heat transfer coefficient for tubes 4-7 at atmospheric pressure with a HEATEX insert. All other U_o data for the rest of the runs are listed in Appendix D.

Figure 20 shows how the outside heat transfer coefficients for tubes 6 and 7 compare with the smooth titanium tube at atmospheric pressure. Tubes 6 and 7 were the only wire-wrapped titanium tubes to show significant enhancement. Both of these tubes were wrapped with a 0.5 mm diameter wire with pitches of 4 mm ($P/D_w = 7.92$) and 2 mm ($P/D_w = 4.02$) respectively. Tube 6 showed enhancements between 23% and 30% for vacuum and atmospheric pressure respectively. Figures 21 and 22 show the outside heat transfer coefficient data for tubes 1 through 5. Tube 3 was the only tube to show a degradation in performance as compared to the smooth titanium tube. It had a 1.6 mm wire with a pitch of 3.40 mm ($P/D_w = 2.13$); the poor performance of this tube is attributed to the effects of condensate retention between the wires on the tube, which were clearly seen. The performance of tubes 1 and 2 were similar to the plain smooth tube. Tubes 4 and 5 showed an enhancement of about 10% over the smooth titanium tube. Tables VII through XI show the results from the data reduction scheme for C_1 and α for each data run. The leading coefficients in front of the inside heat transfer correlation

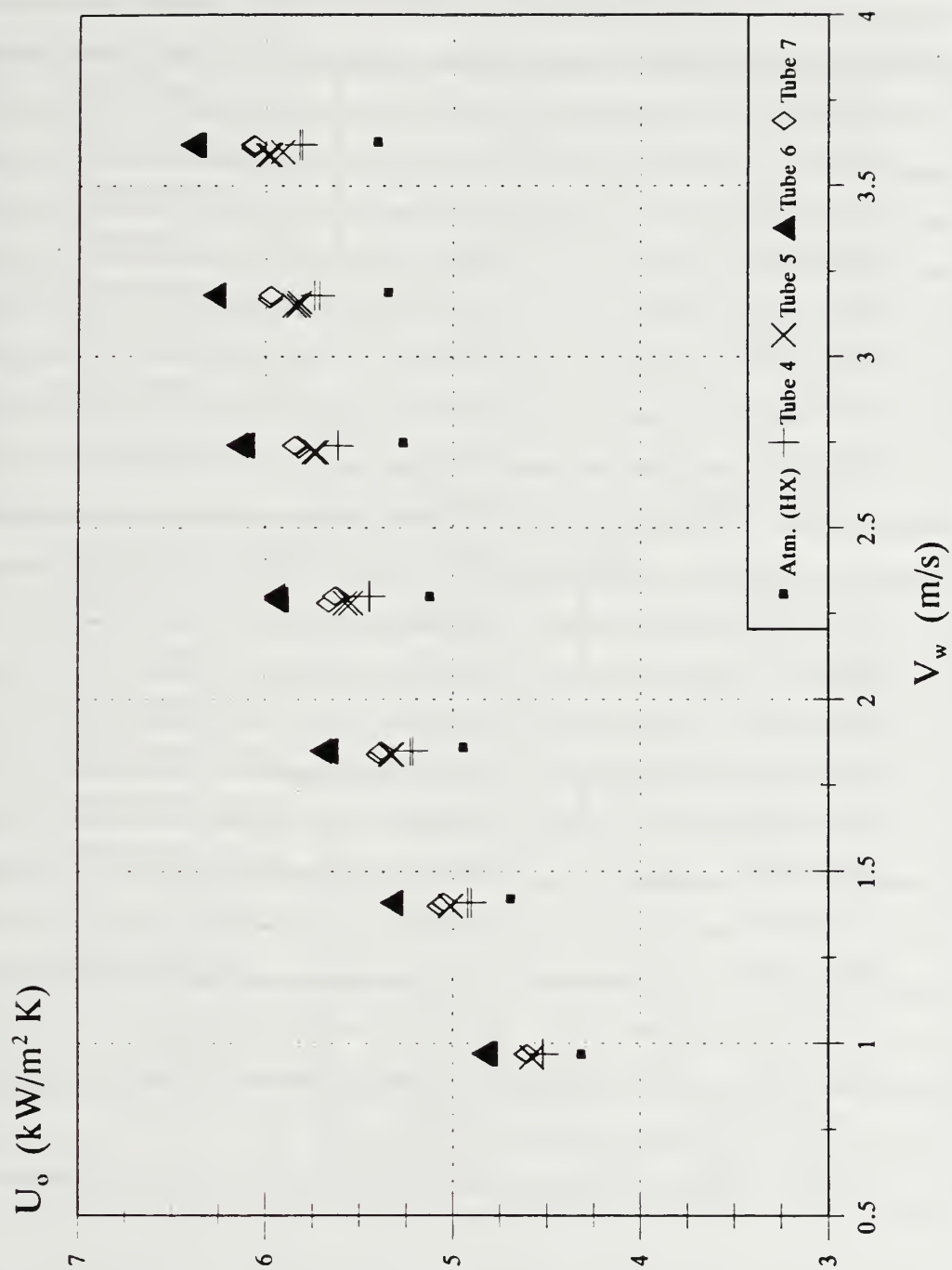


Figure 19. U_o vs V_w for Wire-Wrapped Tubes at Atmospheric Pressure with a Heatex Insert

Table VII. WIRE-WRAPPED SMOOTH TITANIUM TUBES WITH A HEATEX INSERT

Atmospheric Pressure HEATEX Insert			
Data Run / Tube	C_1	α	E_T
FONMAH1T1 (1)	2.023	0.798	1.035
FONMAH2T3 (2)	2.448	0.806	1.046
FONMAH3T1 (3)	2.138	0.724	0.902
FONMAH4T1 (4)	2.379	0.853	1.106
FONMAH5T1 (5)	2.251	0.869	1.127
FONMAH6T2 (6)	2.389	0.993	1.289
FONMAH6T3 (6)	2.362	1.005	1.304
FONMAH7T1 (7)	2.237	0.925	1.200
Atm. Avg.	2.301		
Vacuum Pressure HEATEX Insert			
FONMVH1T1 (1)	1.892	0.802	1.045
FONMVH2T1 (2)	2.005	0.797	1.038
FONMVH2T2 (2)	1.948	0.787	1.026
FONMVH2T3 (2)	2.240	0.766	0.999
FONMVH3T2 (3)	1.866	0.618	0.714
FONMVH4T1 (4)	2.081	0.821	1.071
FONMVH5T1 (5)	2.014	0.842	1.097
FONMVH6T1 (6)	2.160	0.950	1.238
FONMVH6T2 (6)	2.214	0.946	1.233
FONMVH7T2 (7)	1.956	0.855	1.115
Vac. Avg.	1.967		
Total Avg.	2.115		

are consistent with the smooth tube data, as expected.

The copper tubes used by Mitrou [Ref. 9], tubes 68 and 71, were tested to check the repeatability of Mitrou's data. As

Table VIII. WIRE-WRAPPED SMOOTH TITANIUM TUBES WITH NO INSERT

Atmospheric Pressure No Insert			
Data Run / Tube	C_1	α	E_T
FONMAN1T1 (1)	1.131	0.783	1.022
FONMAN2T1 (2)	1.095	0.801	1.047
FONMAN3T1 (3)	1.034	0.698	0.888
FONMAN4T1 (4)	1.377	0.791	1.034
FONMAN5T1 (5)	1.099	0.837	1.093
FONMAN6T1 (6)	1.120	1.019	1.331
FONMAN7T1 (7)	1.191	0.866	1.131
Atm. Avg.	1.150		
Vacuum Pressure No Insert			
FONMVN1T1 (1)	1.024	0.838	1.021
FONMVN2T1 (2)	0.998	0.818	0.997
FONMVN3T1 (3)	0.911	0.636	0.702
FONMAN4T1 (4)	1.139	0.825	1.005
FONMAN5T1 (5)	0.978	0.843	1.027
FONMAN6T1 (6)	1.043	1.013	1.235
FONMVN7T1 (7)	0.978	0.870	1.060
Vac. Avg.	1.010		
Total Avg.	1.080		

discussed earlier, it was difficult to get good filmwise condensation over the entire tube. The enhancements found were higher than those given by Mitrou's data (reprocessed using the Petukhov-Popov correlation) for tubes 68 and 71; for tube 68, differences of 10% and 17% and for tube 71, differences of 45% and 6% for atmospheric and vacuum pressures

Table IX. WIRE-WRAPPED SMOOTH COPPER TUBES WITH A HEATEX INSERT

Atmospheric Pressure HEATEX Insert			
Data Run	C_i	α	E_T
FONMAH68C1	2.807	1.316	1.719
FONMAH71C1	3.069	1.722	2.192
Atm. Avg.	2.938		
Vacuum Pressure HEATEX Insert			
FONMVH68C1	2.549	1.289	1.570
FONMVH71C2	2.765	1.414	1.560
Vac. Avg.	2.657		
Total Avg.	2.797		

respectively. This increase in enhancement could have been due to small patches of dropwise condensation on the surface of the tubes, although it was difficult to see during the experiments due to condensate on the window. Figure 23 shows the comparison of tubes 6 and 71 to a smooth titanium tube. Tubes 6 and 71 have similar pitches and the same wire diameter and should, in theory, give similar values for the outside heat transfer coefficient. However, the enhancement given by the wire-wrapped copper tube (tube 71) is significantly higher ($\approx 35\%$) than the enhancement given by the wire-wrapped titanium tube (tube 6). This trend tends to reiterate the idea that tube surface wettability characteristics or tube thermal conductivity may affect the outside heat transfer coefficient.

Table X. WIRE-WRAPPED SMOOTH COPPER TUBES WITH A WIRE WRAP INSERT

Atmospheric Pressure Wire Wrap Insert			
Data Run/Researcher	C_i	α	E_r
S68A311 (M)	2.686	1.360	1.616
S71A305 (M)	2.685	1.489	1.769
S71A314 (M)	2.692	1.473	1.749
Atm. Avg.	2.688		
Vacuum Pressure Wire Wrap Insert			
S68V283 (M)	2.452	1.182	1.401
S68V293 (M)	2.485	1.166	1.382
S71V296 (M)	2.503	1.267	1.501
Vac. Avg.	2.480		
Total Avg.	2.584		

In order to see the relationship between the wire pitch, wire diameter and the enhancement, the values of enhancement versus the wire pitch to wire diameter ratio are plotted in Figure 24. Also shown are the newly reprocessed data (using the Petukhov-Popov correlation) from Mitrou [Ref. 9], and the data presented by Sethumadhavan and Rao [Ref. 15]. Even though the experiments were conducted very carefully, the titanium tube data tends to show the most scatter. The data of Sethumadhavan and Rao [Ref. 15] and Mitrou [Ref. 9] demonstrate a maximum enhancement at a P/D_w of about 5. The present data do not show such a clear maximum and tube 6 ($P/D_w = 7.96$) does not appear to be in line with the data of Sethumadhavan and Rao or Mitrou. Extra experiments were done

h_o vs. T_{cf}
 Atmospheric Pressure using the Petukhov-Popov Correlation

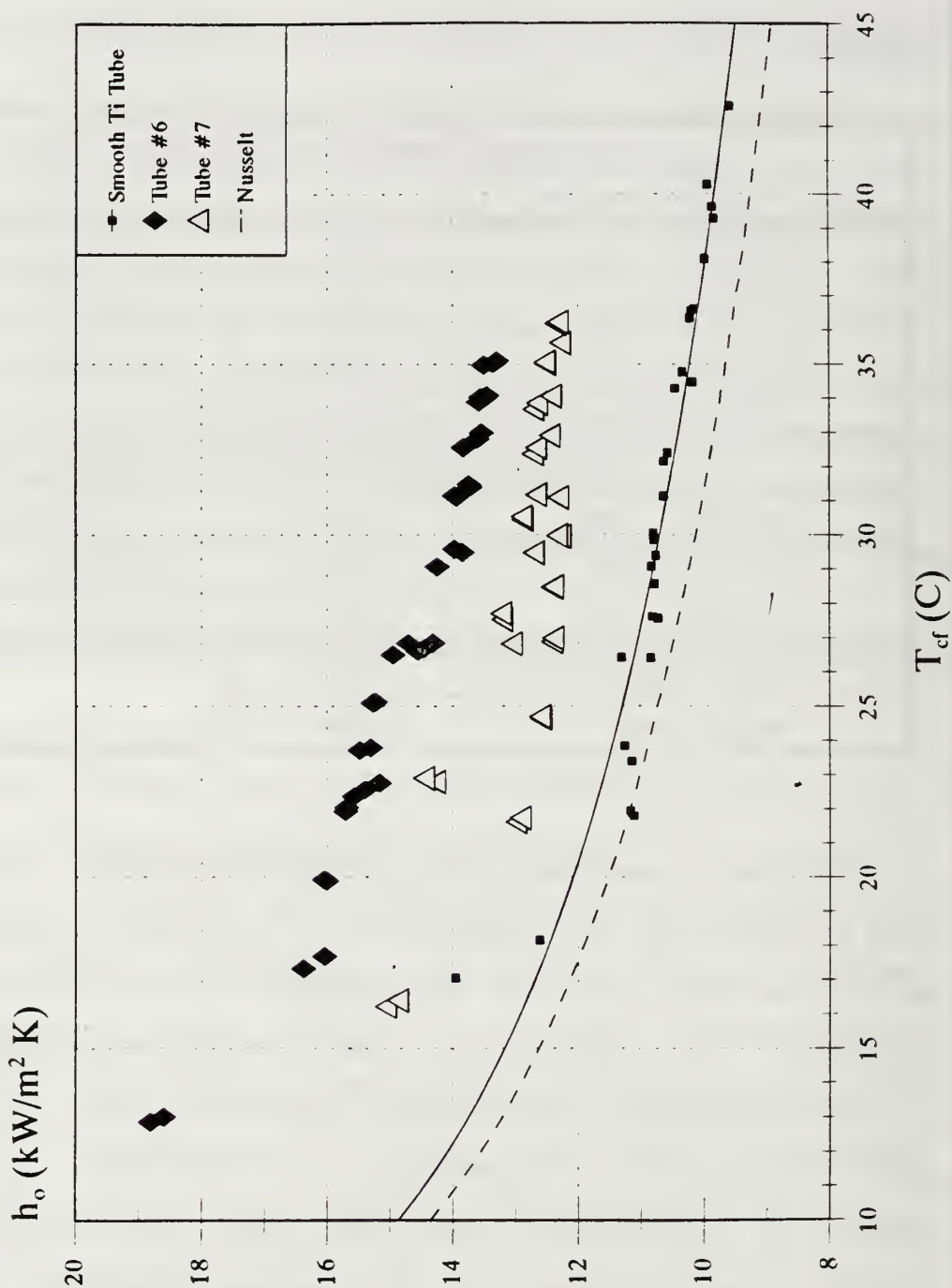


Figure 20. Comparison of the Outside Heat Transfer Coefficients of Tubes 6 and 7 with a Smooth Titanium Tube

h_o VS. T_{cf} Atmospheric Pressure using the Petukhov-Popov Correlation

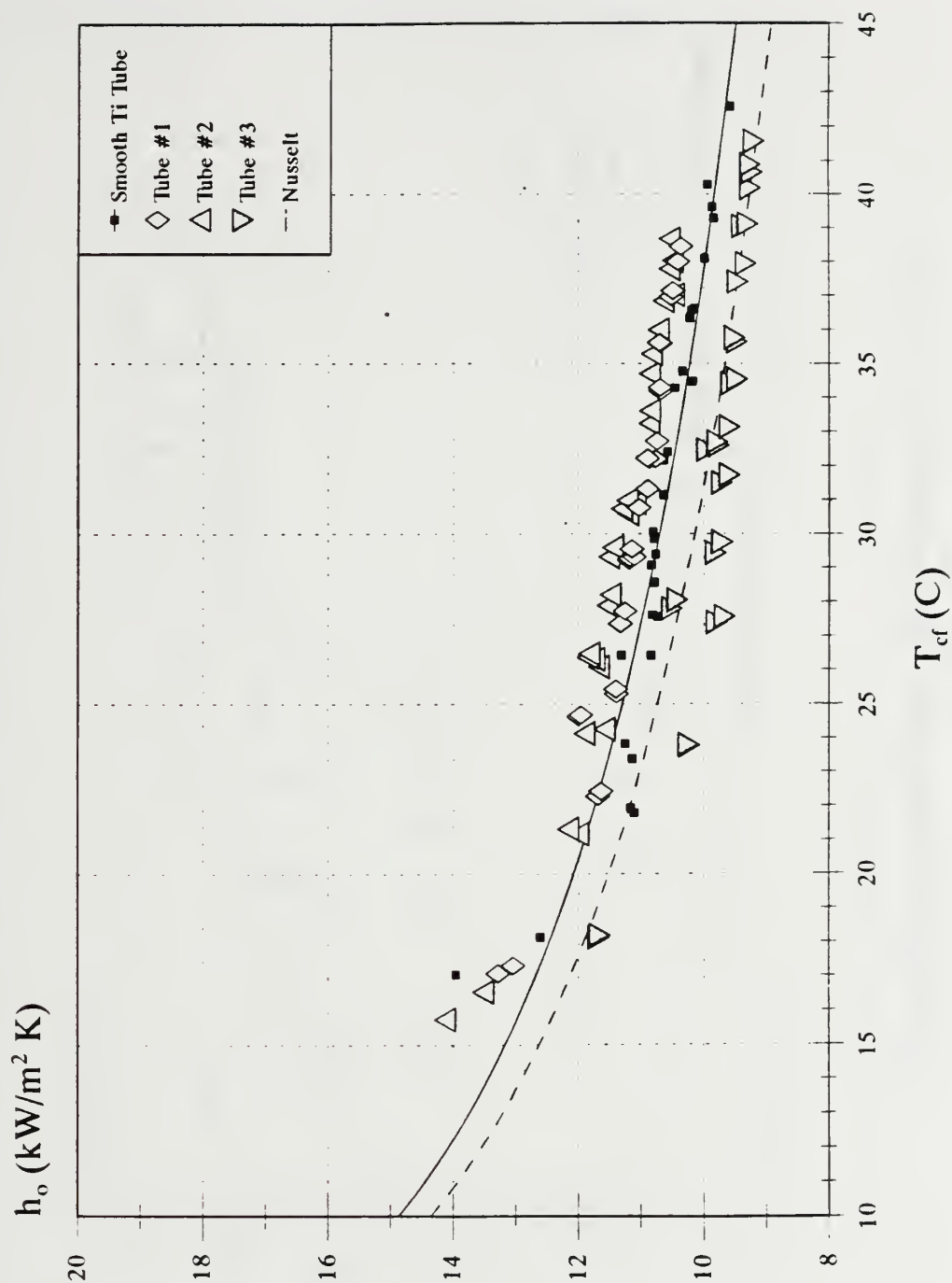


Figure 21. Comparison of the Outside Heat Transfer Coefficients of Tubes 1,2, and 3 to a Smooth Titanium Tube

h_o vs. T_{cf} Atmospheric Pressure using the Petukhov-Popov Correlation

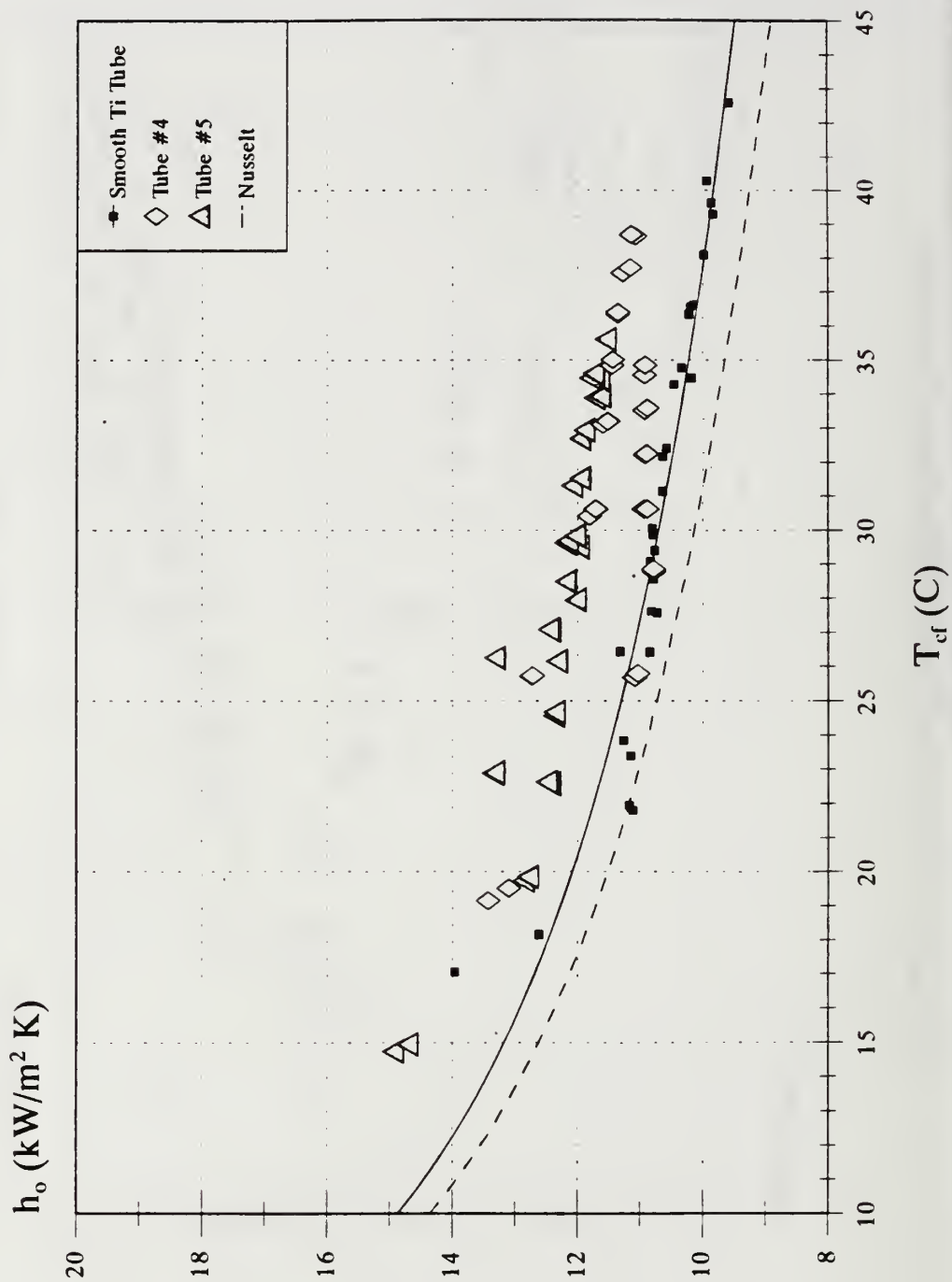


Figure 22. Comparison of the Outside Heat Transfer Coefficients for tubes 4 and 5 to a Smooth Titanium Tube

h_o vs. T_{cf}
 Atmospheric Pressure using the Petukhov-Popov Correlation

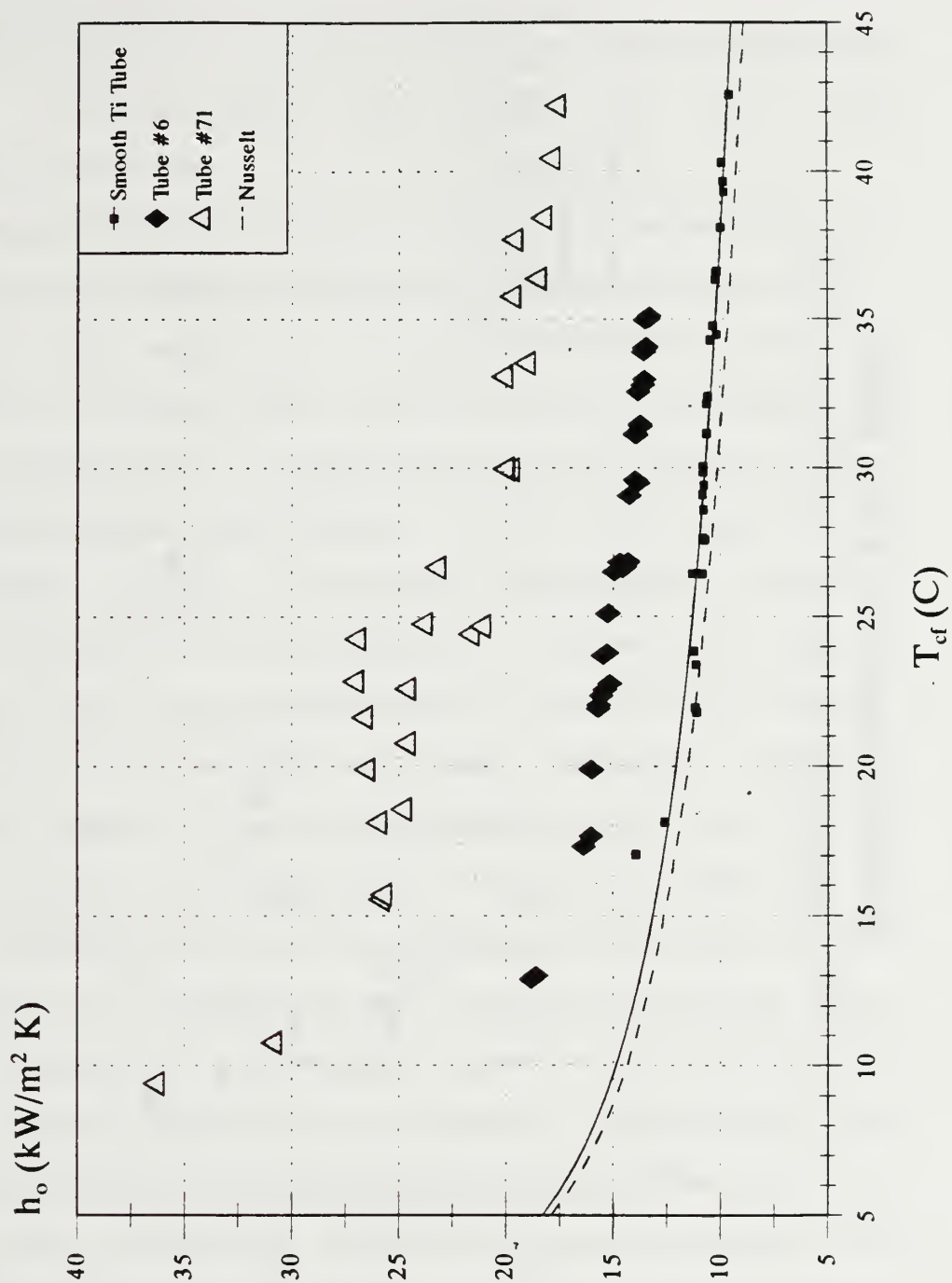


Figure 23. Comparison of the Outside Heat Transfer Coefficients between the Titanium and Copper Tubes

Enhancement vs. P/D_w Ratio

Wire-Wrapped Smooth Tubes at Atmospheric Pressure

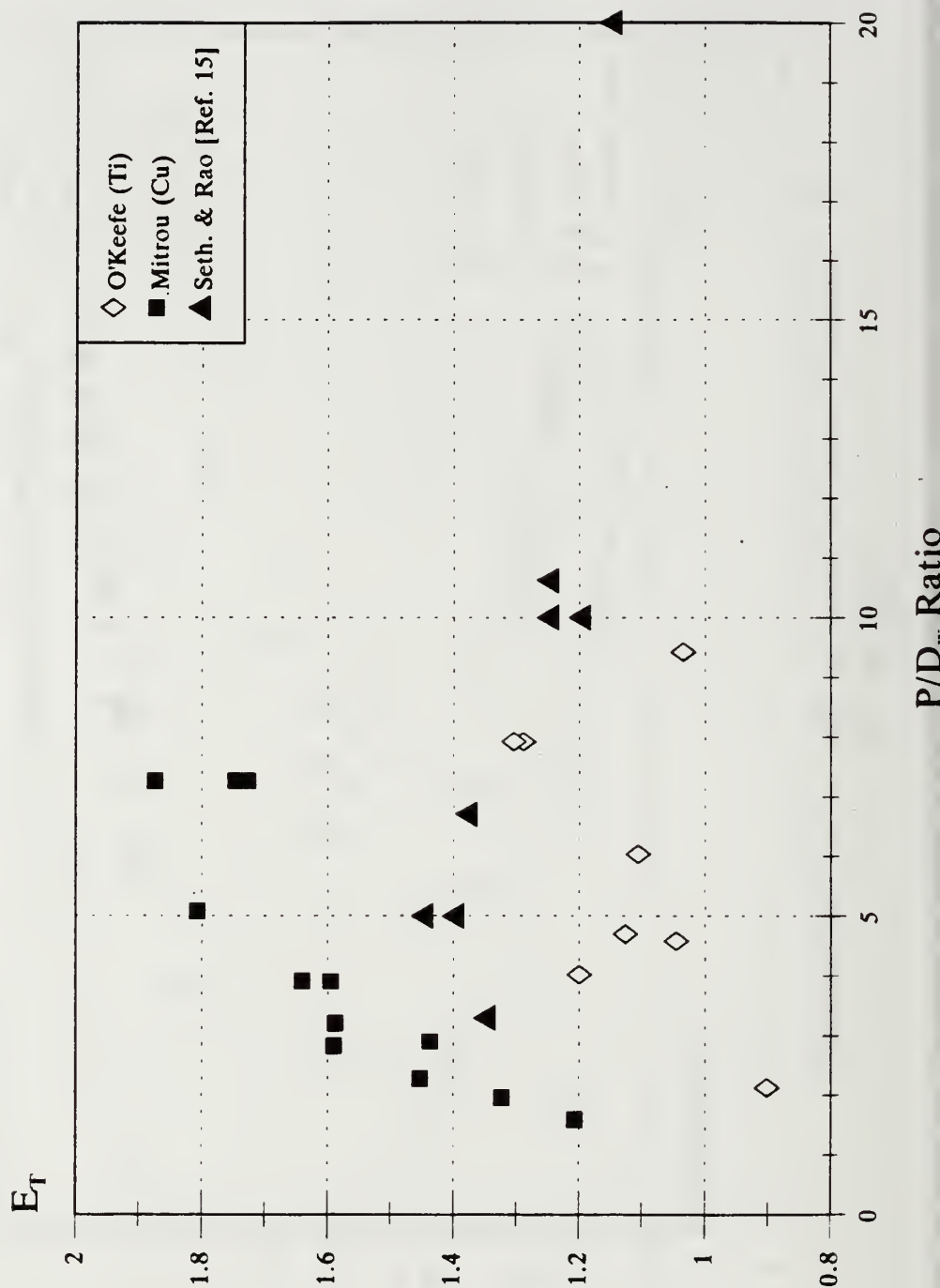


Figure 24. Comparison of the Enhancement vs. P/D_w Ratio of the Data from Mitrou, O'Keefe, and Sethumadhavan & Rao

on tube 6 to check the repeatability with essentially the same results. It would appear that P/D_w is not such a good correlating parameter.

Instead of looking at the P/D_w ratio, the enhancement can also be compared to the percentage of the tube surface that is covered by the wire, F . In the research done by Sethumadhavan and Rao [Ref. 15], the optimal coverage of a tube was found to be 21%. The fractional wire coverage values were determined for the present titanium and copper wire-wrapped tubes. Figure 25 shows the enhancement versus the fraction of the tube covered by wire. The value of 21% for the optimal value of F does not seem to hold for the data in this thesis or for the data of Mitrou. However, this does seem to be a better correlating parameter than P/D_w , and the maximum value of the fractional tube coverage seems to lie somewhere between 10% and 30%. The optimal value of F for the copper tube used by Mitrou and the titanium tube appear to be different and there is a definite increase in F as the tube material thermal conductivity increases. Unfortunately, the material of the tube used by Sethumadhavan and Rao [Ref. 15] is not given, although the data would suggest some intermediate conductivity material such as aluminum. Indeed, in another paper by Mehta and Rao [Ref. 22] aluminum tubes were used.

Enhancement vs. F

Wire-Wrapped Smooth Tubes at Atmospheric Pressure

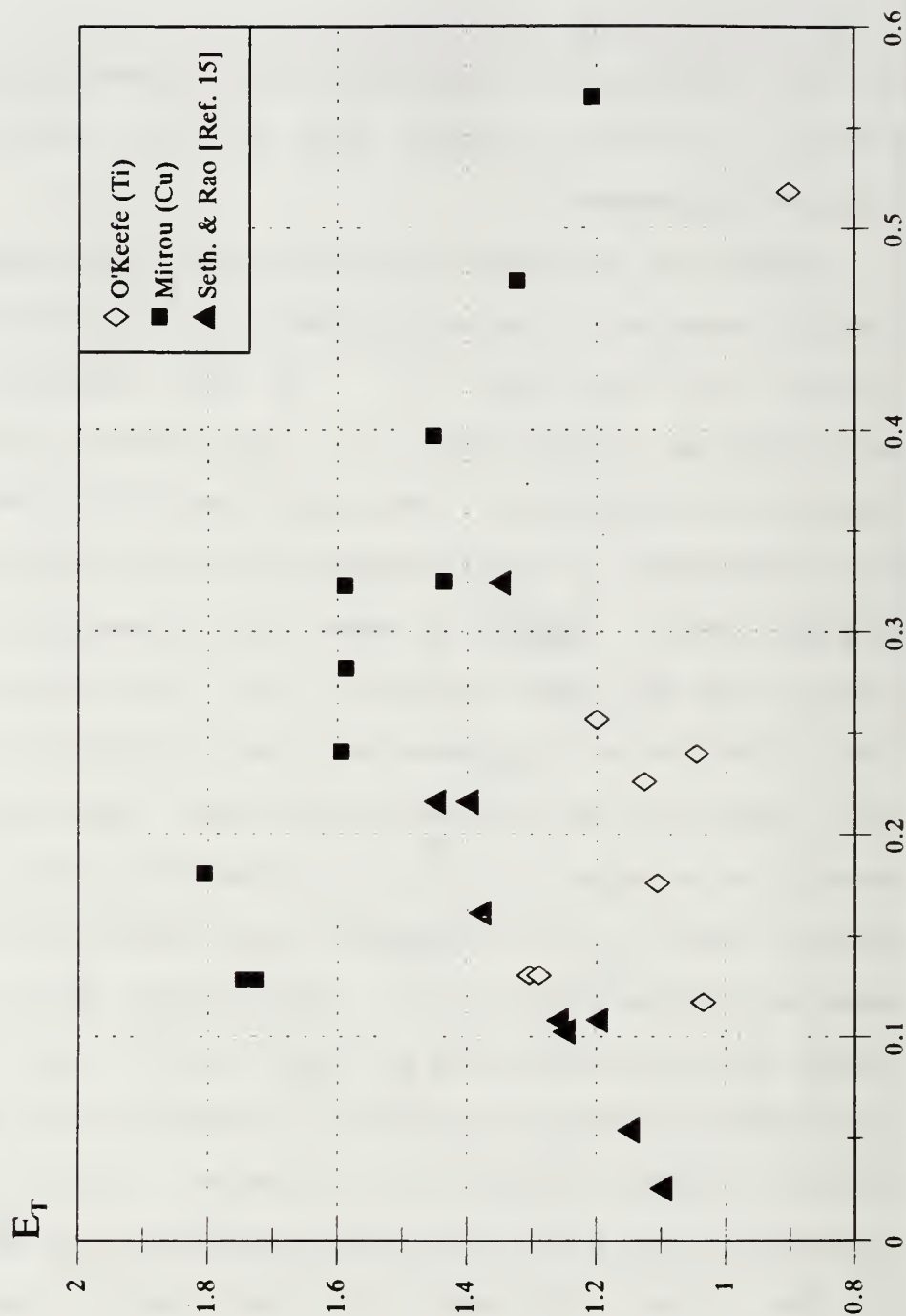


Figure 25. Comparison of the Enhancement vs. F for the data of Mitrou, O'Keefe, and Sethumadhavan & Rao

D. ANALYSIS OF THE ROPED AND WIRE-WRAPPED ROPED TITANIUM TUBES

Four different roped tubes were tested. One tube was a plain LPD KORODENSE titanium tube that was used to get baseline data for comparing to the plain smooth titanium tube and to the wire-wrapped LPD KORODENSE titanium tubes. The values of the overall heat transfer coefficient are much higher ($\approx 20\%$) for the LPD KORODENSE tubes when compared to the plain smooth titanium tube. The reason for the increase in the overall heat transfer coefficient is mainly because of the corrugation of the LPD tube on the inside which increases the turbulence of the coolant flow, thereby reducing the inside thermal resistance.

Tables 12 and 13 give the results of the data reduction procedure of all the roped tubes in comparison with the smooth titanium tube. The plain LPD tube consistently gave enhancements of about 20% in the outside heat transfer coefficient, as seen in Figure 26. The wire-wrap was put on the roped tube to try and get an additional enhancement on the outside of the tube. By looking at Tables 12 and 13, the only wire-wrapped LPD tube that showed any enhancement over the plain LPD tube was tube L3 ($D_w = 0.5$ mm). Figure 27 shows the outside heat transfer coefficients for the three wire-wrapped LPD tubes. The wire-wrapped LPD tubes were also checked to see if there was any relation between P/D_w or F and the enhancement over a plain LPD tube (h_e/h_{LPD}). Figures 28 and 29

h_o vs. T_{cf} Atmospheric Pressure using the Petukhov-Popov Correlation

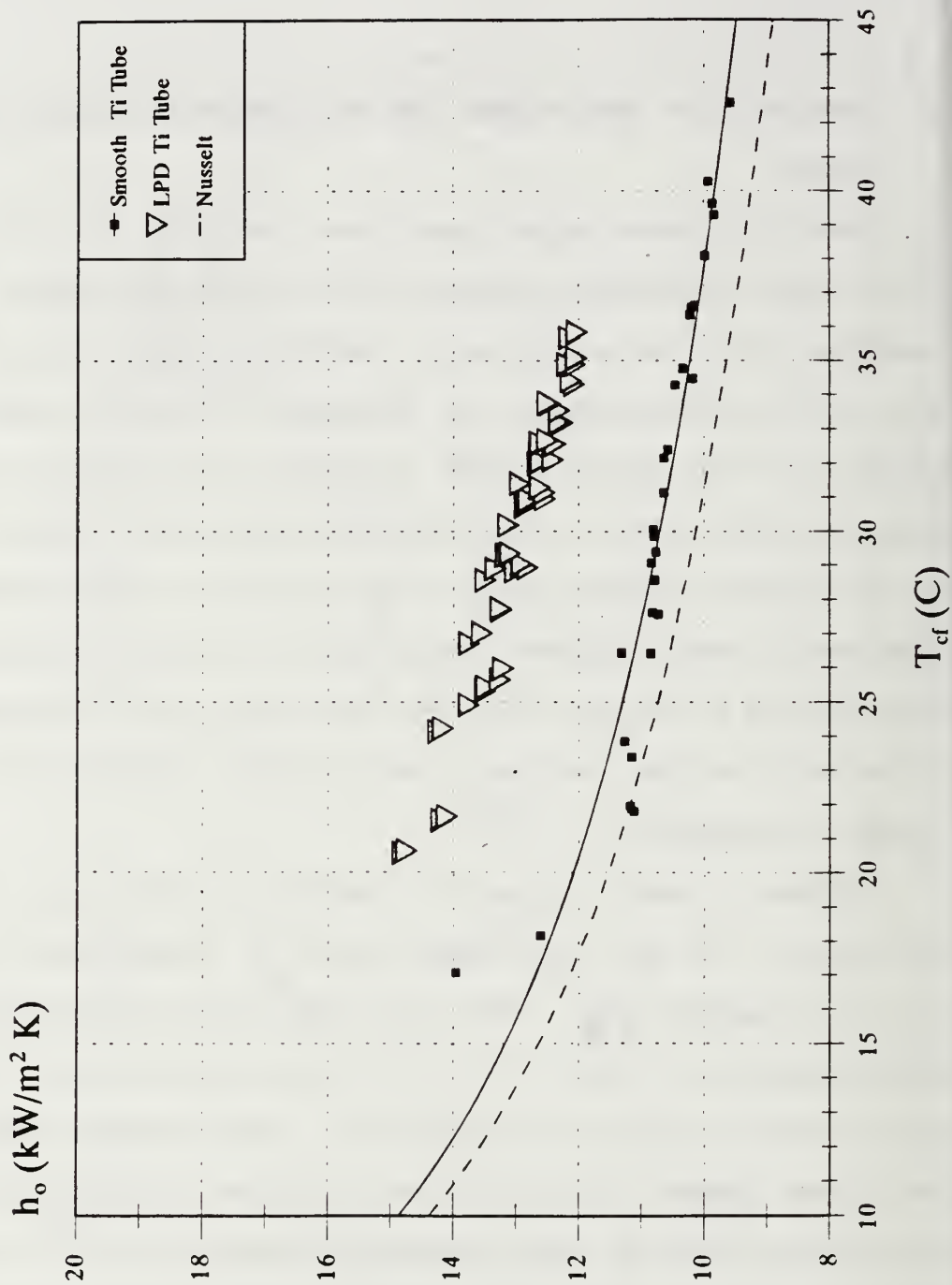


Figure 26. Comparison of the Outside Heat Transfer Coefficients for the plain LPD KORODENSE Tube and the Smooth Titanium Tube

Table XI. LPD KORODENSE TUBES WITH A HEATEX INSERT

Atmospheric Pressure HEATEX Insert			
Data Run / Tube	C_i	α	E_T
FONMAHLT2 (L)	2.903	0.903	1.171
FONMAHLT3 (L)	2.892	0.916	1.188
FONMAHL1T1 (L1)	2.667	0.890	1.154
FONMAHL2T1 (L2)	2.639	0.909	1.179
FONMAHL3T1 (L3)	2.835	0.968	1.256
Atm. Avg.	2.787		
Vacuum Pressure HEATEX Insert			
FONMVHLT1 (L)	2.717	0.945	1.232
FONMVHLT2 (L)	2.669	0.950	1.238
FONMVHL1T2 (L1)	2.317	0.880	1.147
FONMVHL2T3 (L2)	2.426	0.890	1.161
FONMVHL3T2 (L3)	2.609	0.995	1.297
Vac. Avg.	2.548		
Total Avg.	2.667		

show respectively the relationship between P/D_w and F to the enhancement over the plain LPD tube. Since the pitch here is fixed, Figure 28 indicates that there may be further enhancement possible if a smaller diameter wire is used. Figure 29 suggests there may be an optimal fractional coverage of the tube between 0 and 0.07. Based on the results from the wire-wrapped smooth titanium tubes, the maximum enhancement seen was about 30%; for the plain LPD tube over the plain smooth titanium tube the enhancement was about 20%.

Table XII. LPD KORODENSE TUBES WITH NO INSERT

Atmospheric Pressure No Insert			
Data Run / Tube	C_1	α	E_T
FONMANLT2 (L)	2.056	0.919	1.201
FONMANLT3 (L)	1.993	0.941	1.230
FONMANL1T1 (L1)	2.036	0.869	1.135
FONMANL2T1 (L2)	2.057	0.890	1.163
FONMANL3T1 (L3)	2.202	0.933	1.219
Atm. Avg.	2.069		
Vacuum Pressure No Insert			
FONMVNLT2 (L)	1.869	0.953	1.161
FONMVNLT3 (L)	1.862	0.956	1.165
FONMVNL1T2 (L1)	1.784	0.855	1.041
FONMVNL2T3 (L2)	1.839	0.869	1.059
FONMVNL3T2 (L3)	2.041	0.942	1.148
Vac. Avg.	1.879		
Total Avg.	1.974		

Therefore, the maximum additional enhancement expected from wire-wrapping the LPD tube with a smaller diameter wire would be about 10%.

One reason the larger diameter wires did not improve the outside enhancement of the LPD tubes is that there was more condensate retained between the wires than with the plain LPD tube. This additional condensate causes a thicker condensate film across the lower portion of the tube, resulting in less overall heat transfer. The smallest wire (0.5 mm) fitted into

h_o vs. T_{cf}

Atmospheric Pressure using the Petukhov-Popov Correlation

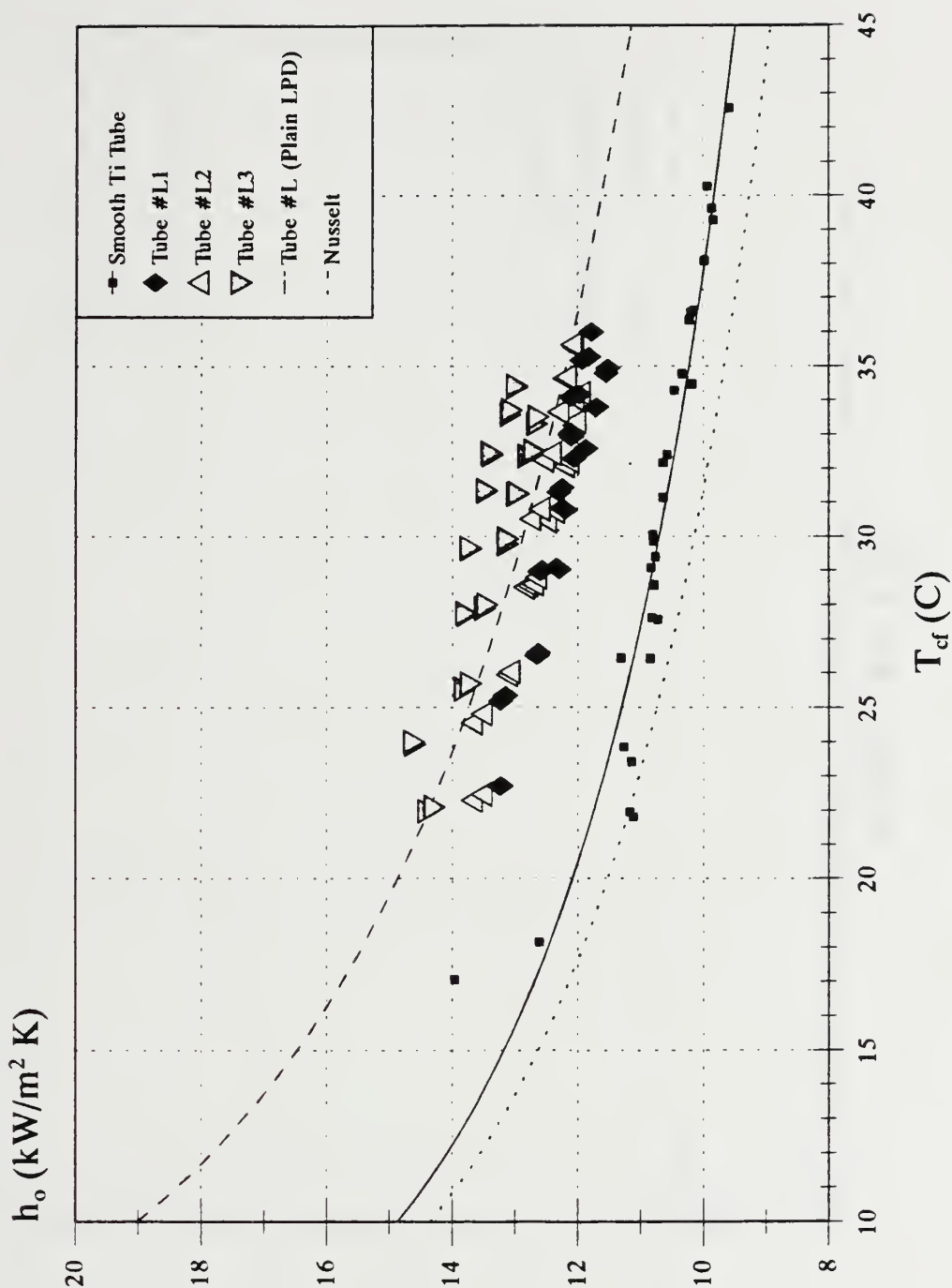


Figure 27. Comparison of the Outside Heat Transfer Coefficient for the Wire-Wrapped LPD KORODENSE Titanium Tubes and the Smooth Titanium Tube

$$h_e/h_{LPD} \text{ vs. } P/D_w$$

Wire-Wrapped LPD KORODENSE Titanium Tubes at Atmospheric Pressure

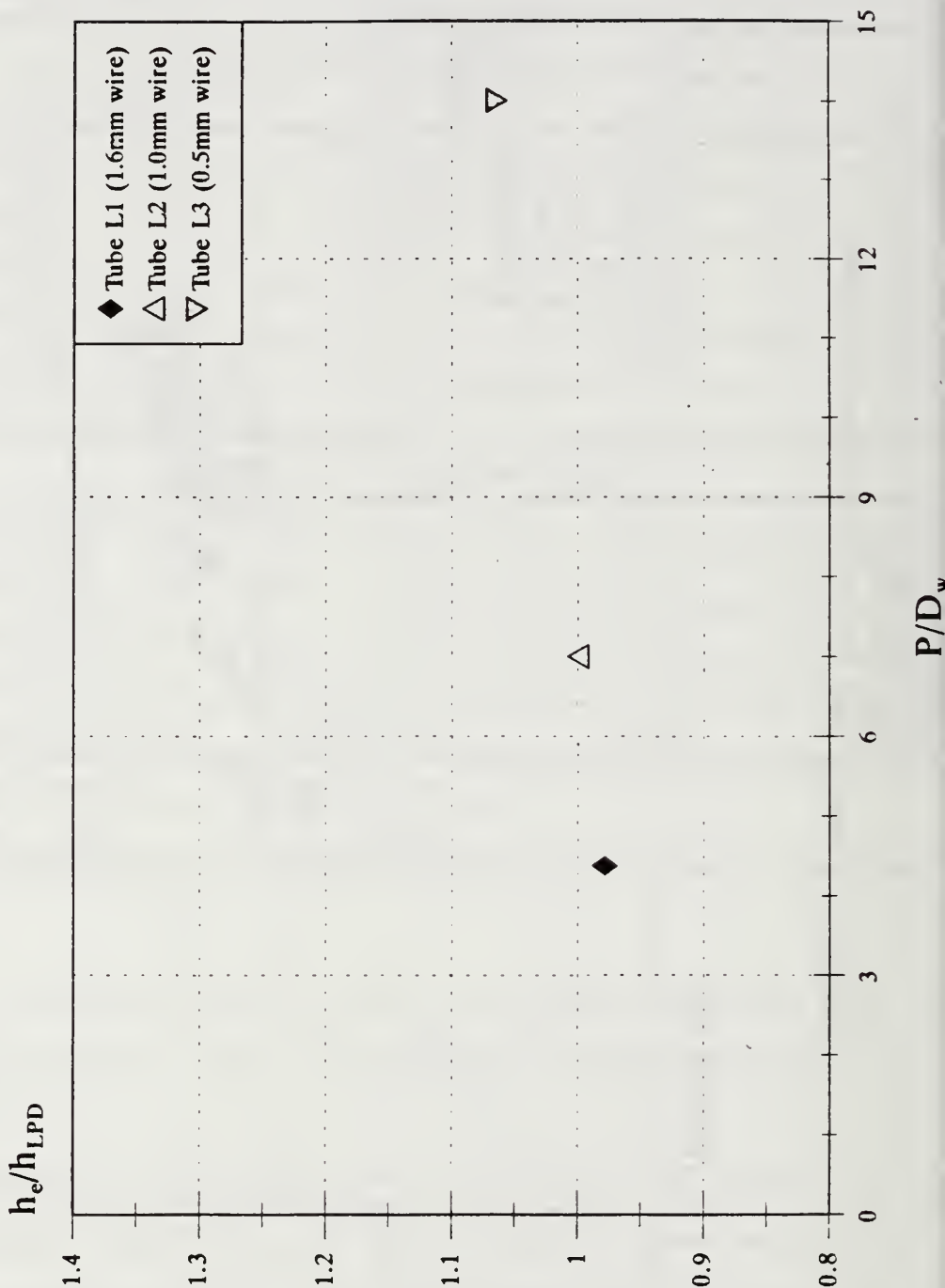


Figure 28. Comparison of $h_e/h_{o.s.}$ vs. P/D_w Ratio for the Wire-Wrapped LPD KORODENSE Tubes

h_e/h_{LPD} vs. F Wire-Wrapped LPD KORODENSE Titanium Tubes

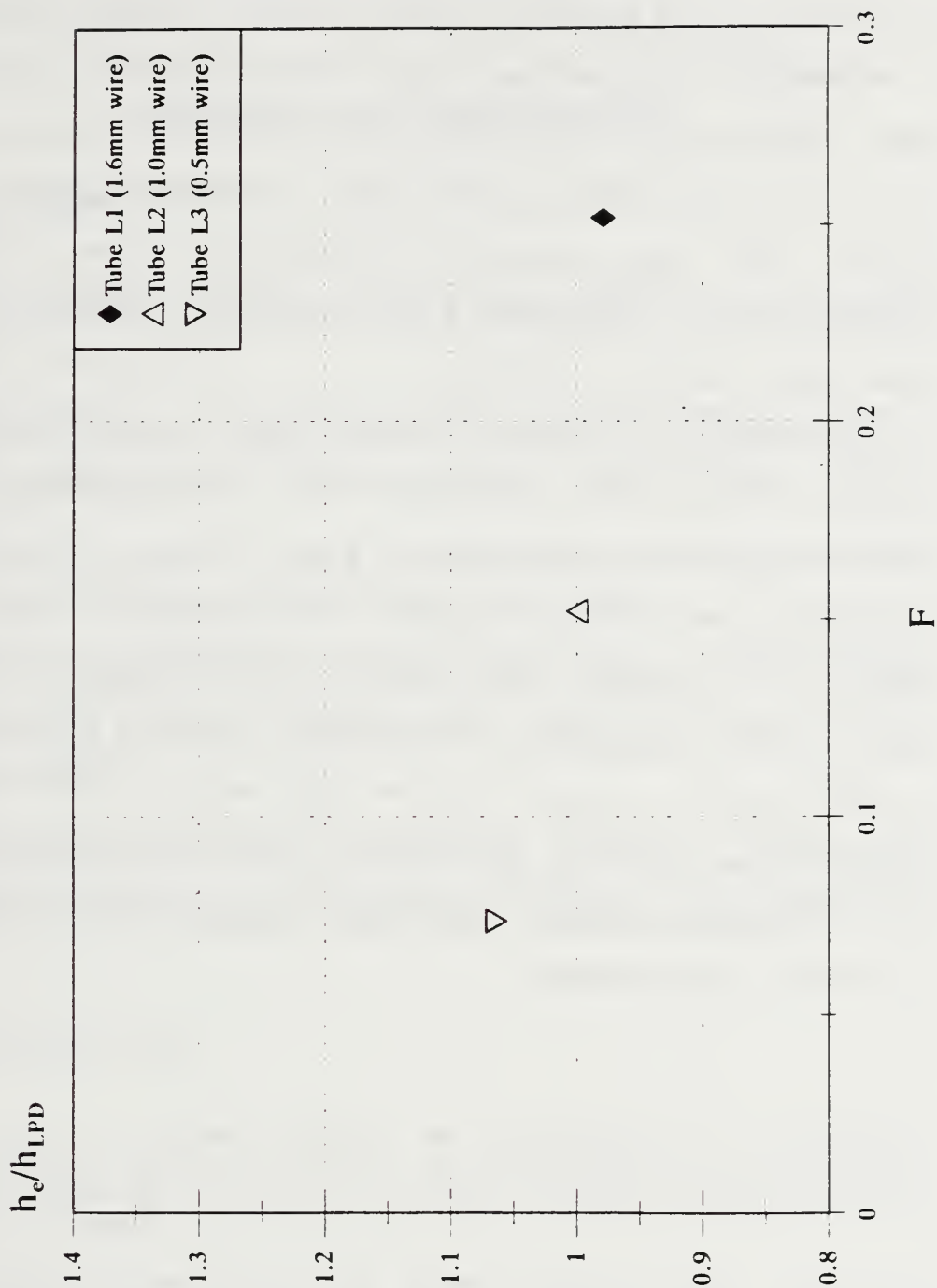


Figure 29. Comparison of h_e/h_{LPD} vs. F for the Wire-Wrapped LPD KORODENSE tubes

the groove of the roped tube more closely, so that the amount of condensate retained was about the same as for a plain LPD tube. Since there was no additional condensate retention, the wire was better able to draw the condensate film to the groove. The larger pressure differential leads to greater thinning of the condensate film and thus a reduction in the vapor side thermal resistance.

In summary, the maximum enhancement in the outside heat transfer coefficient realized for a wire-wrapped smooth titanium tube was $\approx 30\%$ with a $P/D_w = 7.96$. A plain LPD KORODENSE tube showed consistent enhancements of $\approx 20\%$ in the outside heat transfer coefficient when compared to a smooth tube. There only seems to be a minimal gain in wire-wrapping an LPD tube to further improve the outside heat transfer coefficient. However, one benefit to wire-wrapping an LPD tube would be to reduce the effects of condensate inundation in a bundle arrangement.

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. The Petukhov-Popov inside heat transfer coefficient correlation can be used to give accurate results in this test apparatus.
2. Enhancements in the outside heat transfer coefficient of up to 30% were obtained using a wire-wrapped titanium tube, when compared to the smooth titanium tube. ($P/D_w = 7.92$)
3. An optimal value of the fractional wire coverage of the tube of between 10% and 30% was found.
4. For an LPD KORODENSE titanium roped tube, an enhancement in the outside heat transfer coefficient of up to 20% over the smooth titanium tube was obtained. Using a wire-wrap on the LPD KORODENSE tube showed little further enhancement.
5. The surface wettability characteristics and perhaps the thermal conductivity of the tube material seems to have an influence on the outside heat transfer coefficient and possibly the optimal fractional wire coverage.

B. RECOMMENDATIONS

1. A set of tubes should be fabricated of different materials with fractional wire coverage of the tube in the range of 0.1 to 0.3, using different wire diameters and pitches.
2. Determine the effect of vapor velocity and inundation effects on the titanium wire-wrapped tubes. Use the Fujii [Ref. 12] correlation for the outside heat transfer coefficient when reprocessing the data.
3. Fabricate several more wire-wrapped LPD KORODENSE tubes using thinner wire diameters (0.1 mm, 0.2 mm, and 0.3 mm). To determine if there is a significant increase in

the enhancement of the outside heat transfer coefficient and an optimal value for the fractional wire coverage of the tube.

4. Reprocess the data sets using all the data for a given configuration (i.e. pressure, insert used, etc...) to determine more accurate values of C_1 and α .
5. Conduct bundle tests to see if condensate inundation is reduced with wire-wrapped smooth and roped tubes.

APPENDIX A. SYSTEM CORRECTIONS

A. FRICTIONAL TEMPERATURE CORRECTIONS

When the coolant flows through the tube there is a temperature rise in the bulk fluid due to frictional heating. The amount of heating is dependent on the fluid velocity and the inside geometry of the tube. The actual temperature is small, but it can have a significant effect on the calculation for the overall heat transfer coefficient. The titanium tubes had a smaller temperature rise across the tube than the copper tubes, so the effect of the frictional heating is much greater. Measurements were made for the smooth titanium tube on August 7, 1992 and August 14, 1992 for the LPD KORODENSE titanium tube. The data is plotted in Figures A.1 and A.2. Runs were conducted with and without the HEATEX insert. The data was curve fitted to a third order polynomial as shown in Table A.1.

Table A.1 FRICTION TEMPERATURE RISE EQUATIONS

<u>Tube/Insert Type</u>	<u>Polynomial Equation</u>
Smooth/None	$T_{rise} = -8.843 \times 10^{-5} V^3 + 1.799 \times 10^{-3} V^2 - 7.526 \times 10^{-4} V - 4.617 \times 10^{-5}$
Smooth/HEATEX	$T_{rise} = -3.305 \times 10^{-5} V^3 + 2.122 \times 10^{-3} V^2 + 9.737 \times 10^{-4} V + 2.091 \times 10^{-4}$
LPD/None	$T_{rise} = 4.133 \times 10^{-5} V^3 + 6.013 \times 10^{-4} V^2 + 1.880 \times 10^{-3} V - 3.386 \times 10^{-4}$
LPD/HEATEX	$T_{rise} = -2.781 \times 10^{-5} V^3 + 1.893 \times 10^{-3} V^2 + 9.202 \times 10^{-4} V + 2.089 \times 10^{-4}$
where:	$T_{rise} = \text{temperature rise (}^{\circ}\text{K)}$ $V = \text{fluid velocity (m/s)}$

Smooth Titanium Tube

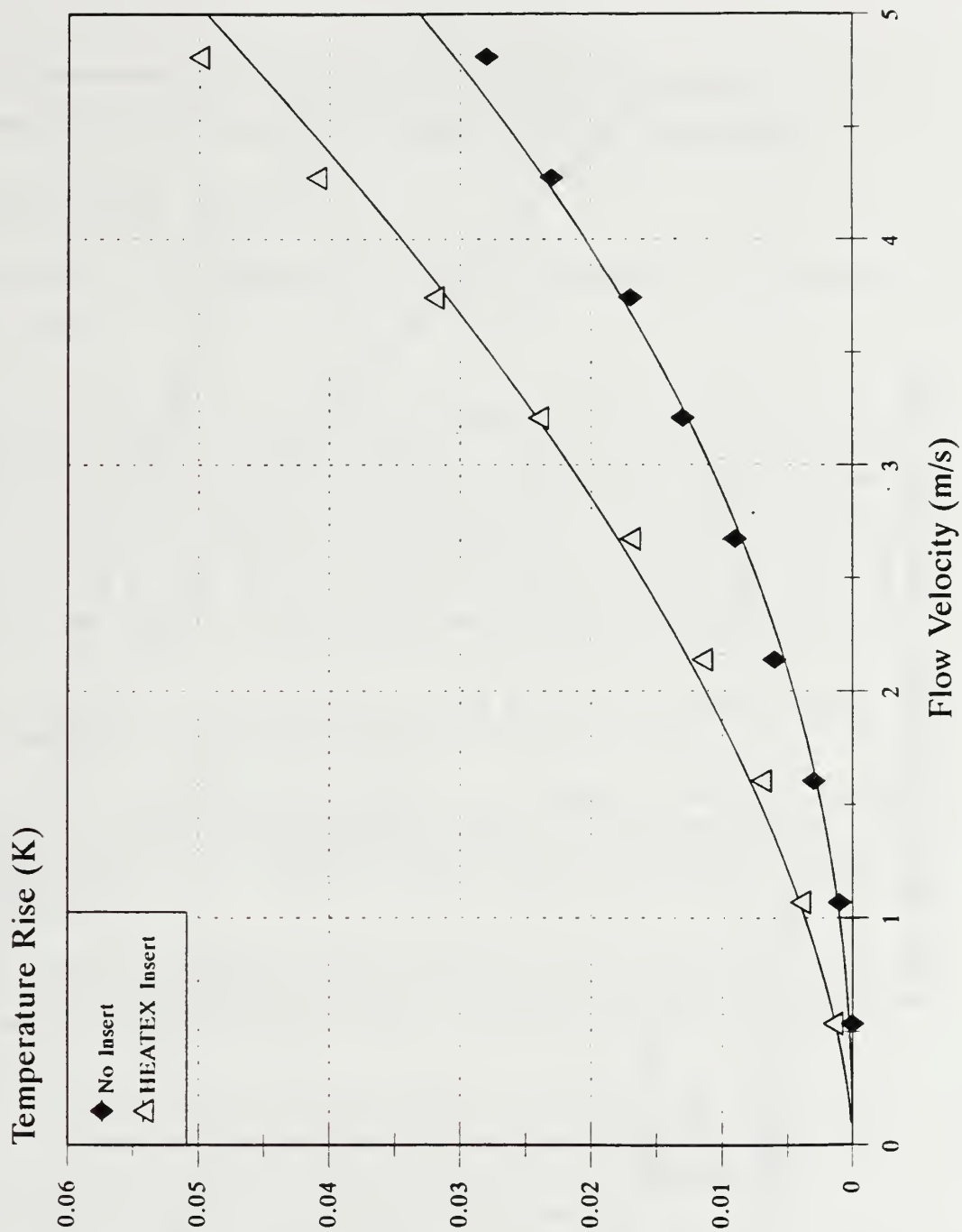


Figure A.1 Frictional Temperature Rise Curves for the Smooth Titanium Tube with a HEATEX Insert and No Insert.

LPD KORODENSE Titanium Tube

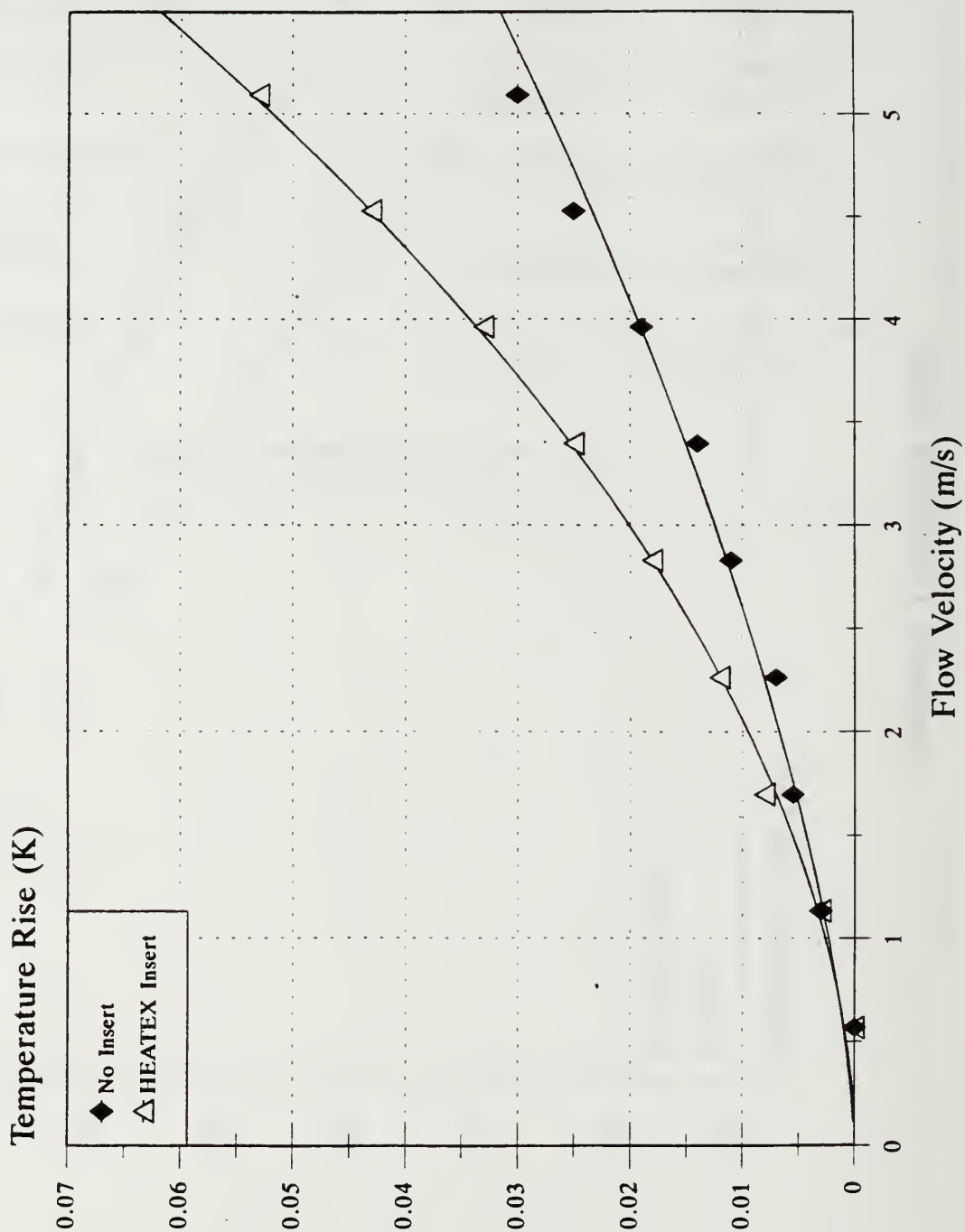


Figure A.2 Frictional Temperature Rise Curves for the LPD KORODENSE Titanium Tube with a HEATEX Insert and No Insert

APPENDIX B. SYSTEM STARTUP AND SHUTDOWN PROCEDURES

A. SYSTEM STARTUP PROCEDURE

When preparing the system for taking data the following should be done:

1. Ensure the boiler section of the system is filled with distilled water, approximately 4 to 6 inches above the heaters. To fill the boiler a hose is attached between the distilled water tank and the boiler fill/drain valve. Ensure the vent valve by the auxiliary condenser is open prior to gravity filling the boiler. The boiler can be drained by ensuring the hose is removed from the boiler fill/drain valve. Then open the fill/drain valve and let the water drain to the bilge area below the boiler.
2. If the boiler has the appropriate water level then ensure the vent valve and fill/drain valve are shut.
3. Energize the data acquisition system, computer, and printer. Load the software program DRPOK and check for proper operation. Before starting any heaters check all thermocouples to ensure they are reading ambient temperature.
4. Open the fill valve to the coolant sump tank and set the flow rate such that the drain box does not overflow. (the valve is located to the left of the boiler heater control panel.)
5. Turn on the cooling water supply pumps and set the flow rate between 40% to 60% and check for leaks in the test section. Secure the flow and coolant supply pumps.
6. Open the valve supplying water to the auxiliary condenser unit and adjust the flow rate to at least 30% and check for leaks in the system. When the leak check is complete reset the flow rate as desired but at least greater than 10%.
7. CAUTION: prior to energizing any heaters ensure that the system is under a vacuum. To draw a vacuum on the system, ensure the drain valve on the plexiglas container

is shut. Check that there is flow to the sump tank, then energize the vacuum pump and open the suction valve located on the side of the auxiliary condenser. Allow the vacuum pump to run until the system pressure is below 3 psia, then shut the suction valve and secure the vacuum pump.

8. The heaters may be energized if the system is confirmed to be under vacuum conditions. To energize the heaters three switches must be placed in the "ON" position. The first switch is located on power panel p5, switch #3, in the main hallway adjacent to H-106. The second switch, the heater load bank circuit breaker, is located on the left side of the boiler heater control panel. The final switch, the condensing rig boiler power switch, is located on the front of the boiler heater control panel. When the heaters are energized, the power level should be set at 50 volts (40 volts if the system is below 2 psia to limit the vibrational shock to the system from vapor bubble formation). As the system warms up, the power can be increased at 10 volt increments until the desired setting is reached.
9. As the system warms up and the system pressure rises above 4 psia, then the non-condensable gases need to be flushed out of the system by drawing a vacuum on the system following step 7. To ensure the non-condensable gases collect at the base of the auxiliary condenser, coolant flow should remain secured and the flow rate to the auxiliary condenser adjusted until all the gases have been purged from the system. When the auxiliary condenser is warm to the touch everywhere, this is an indication that steam is filling the entire condenser and little or no non-condensable gases remain. To initially purge the system of non-condensable gases may take between 15 and 30 minutes. The process should be done every few hours if extended operation of the system is required.
10. To ensure that filmwise condensation is established on the tube being tested, the following should be done:
 - a. Allow the apparatus to warm up to a vapor temperature of at least 3800 microvolts.
 - b. Raise the auxiliary coolant flow rate to 50% or 60% to cool the vapor temperature to approximately 3200 microvolts.

- c. Secure coolant flow to the auxiliary condenser and allow the vapor temperature to rise to about 3700 microvolts. This forms a steam blanket over the tube.
 - d. Initiate coolant flow of 80% in the auxiliary condenser.
 - e. Adjust the coolant flowrate in the auxiliary condenser to maintain the desired temperature and pressure for the system.
11. Run the software program DRPOK by pressing the "run" key on the keyboard. The program will prompt you with questions for the necessary information it needs as follows:
- Select option ... Enter 0 for taking new data
 - Select fluid ... Enter 0 for water
 - Enter input mode ... Enter 0 for new data
 - Enter month, date, time ... when finished press enter
 - Select C_1 ... 0 to find C_1 and 1 to use the program value
 - Give a name for the raw data set ... enter the name
 - Enter the geometry code ... select plain or finned
 - Enter the insert type used... select the appropriate value
 - Enter the tube type ... select the appropriate value
 - Select the tube enhancement used ... select the appropriate value
 - Select the tube material ... enter 0 for copper
 - Select the tube diameter ... enter 1 for medium
 - Enter the pressure condition ... 0 vacuum, 1 atmospheric
 - Select the inside correlation ... 0 Sieder-Tate,
2 Petukhov-Popov
 - Select the outside theory for analysis ... 0 Nusselt or
1 Fujii

- Select the measurement device ... 1 Quartz thermometer
 - Select the output ... 0 short, 1 long
 - Like to check NG concentration ... 1 yes, 2 no
 - Enter flowmeter reading (%) ... enter a 2 digit number
 - Connect voltage line ... flip up voltage line toggle switch on and press enter
 - Disconnect voltage line ... flip voltage line toggle off and press enter
 - Enter pressure gage reading ... input reading from Heise gage and press enter
 - Change TCOOL rise? ... 1 yes, 2 no
 - OK to store this point? ... 1 yes, 2 no
 - Will there be another run? ... 1 yes, 0 no; if yes it returns to the step Like to check NG concentration for following runs
12. Prior to continuing past the question "Enter the flowmeter reading" ensure the system has been operating at steady-state conditions for at least 30 minutes.
 13. **WARNING:** carefully monitor vapor pressure during warmup, especially around atmospheric pressure, to ensure an overpressure condition does not occur.
 14. Vacuum runs are conducted at a heater setting of 90 volts and 1980 ± 10 microvolts on channel 40. This corresponds to $T_{\text{sat}} \approx 48^{\circ}\text{C}$, and a vapor velocity of ≈ 2 m/s.
 15. Atmospheric runs are performed at a heater setting of 175 volts and 4280 ± 10 microvolts on channel 40. This corresponds to $T_{\text{sat}} \approx 100^{\circ}\text{C}$, and a vapor velocity of ≈ 1 m/s.
 16. The viewing window can be cleared of condensation by using heated air from a blow dryer on the glass. **CAUTION:** be careful not to overheat and crack the glass.

17. When taking readings always double check the flowmeter reading prior to accepting any data point. Also, always conduct vacuum runs prior to atmospheric runs because it takes too long for the system to cool down to the vacuum operating temperatures. When trying to conduct both atmospheric and vacuum runs in the same day.

B. SYSTEM SHUTDOWN PROCEDURES

When completed taking data, the system should be secured with the following procedure:

1. Secure power to the heating elements. Turn off the switches on the boiler heater control panel.
2. Secure coolant flow in the auxiliary condenser. If the system is to remain at vacuum pressure until the next data run, then the auxiliary condenser can be used in assisting to cool the system down.
3. Secure the coolant water through the tube by securing the coolant pumps.
4. Secure the water flow to the coolant sump tank.
5. To return the system to atmospheric temperature, slowly open the vent valve on the auxiliary condenser. Ensure no foreign material is in the vicinity of the vent valve so the system does not get contaminated.
6. If an emergency should arise, such as an overpressurization or breakage, ensure the heater power is secured first! Let the system cool down prior to checking for damage.

APPENDIX C. UNCERTAINTY ANALYSIS

Uncertainties are always associated with any experimentally determined results. These uncertainties are a result of many different factors including the accuracy of measuring devices, calibration of a device, and operator experience. Although the uncertainty of a single measurement may be small, when combined with other measurements that have small uncertainties into a data reduction scheme, the effect may be to generate a large uncertainty in the final result.

The uncertainties can be estimated by using a propagation of error technique derived by Kline and McClintock [Ref. 33]. The uncertainty in a quantity, R , is a function of those variables that are used to determine that quantity. So the uncertainty of R can be represented as follows:

$$W_R = \left[\left(\frac{\partial R}{\partial x_1} W_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} W_2 \right)^2 + \dots + \left(\frac{\partial R}{\partial x_n} W_n \right)^2 \right] \quad (C.1)$$

where:

W_R = the uncertainty of the desired dependent variable

$x_1, x_2, \dots, x_n$ = the measured independent variables

$W_1, W_2, \dots, W_n$ = the uncertainties of the measured variables

A complete description for the uncertainty analysis is given in Georgiadis [Ref. 34]. A program, originally designed

by Mitrou [Ref. 9], was used to calculate the uncertainties for this experiment. Sample outputs of the uncertainty evaluations are enclosed.

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVNC1
 Pressure Condition: Vacuum
 Vapor Temperature = 48.626 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 4.32 (m/s)
 Heat Flux = 1.461E+05 (W/m^2)
 Tube-metal thermal conduc. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0179

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.14
Heat Flux, q	1.66
Log-Mean-Tem Diff, LMTD	1.38
Wall Resistance, Rw	2.67
Overall H.T.C., Uo	2.16
Water-Side H.T.C., Hi	11.22
Vapor-Side H.T.C., Ho	11.87

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVNC1
 Pressure Condition: Vacuum
 Vapor Temperature = 48.619 (Deg C)
 Water Flow Rate (%) = 20.00
 Water Velocity = 1.16 (m/s)
 Heat Flux = 8.492E+04 (W/m^2)
 Tube-metal thermal conduc. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0179

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.01
Reynolds Number, Re	3.12
Heat Flux, q	3.11
Log-Mean-Tem Diff, LMTD	.64
Wall Resistance, Rw	2.67
Overall H.T.C., Uo	3.18
Water-Side H.T.C., Hi	11.46
Vapor-Side H.T.C., Ho	43.62

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHC1
 Pressure Condition: Vacuum
 Vapor Temperature = 48.745 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 4.32 (m/s)
 Heat Flux = 1.840E+05 (W/m^2)
 Tube-metal thermal conduc. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0415

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.15
Heat Flux, q	1.43
Log-Mean-Tem Diff, LMTD	1.10
Wall Resistance, R _w	2.67
Overall H.T.C., U _o	1.81
Water-Side H.T.C., H _i	4.92
Vapor-Side H.T.C., H _o	3.41

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHC1
 Pressure Condition: Vacuum
 Vapor Temperature = 48.733 (Deg C)
 Water Flow Rate (%) = 20.00
 Water Velocity = 1.16 (m/s)
 Heat Flux = 1.251E+05 (W/m^2)
 Tube-metal thermal conduc. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0415

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.02
Reynolds Number, Re	3.13
Heat Flux, q	3.08
Log-Mean-Tem Diff, LMTD	.43
Wall Resistance, R _w	2.67
Overall H.T.C., U _o	3.11
Water-Side H.T.C., H _i	5.44
Vapor-Side H.T.C., H _o	10.09

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMANC1
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 99.919 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 4.31 (m/s)
 Heat Flux = 4.227E+05 (W/m²)
 Tube-metal thermal conduc. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0193

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.16
Heat Flux, q	1.04
Log-Mean-Tem Diff, LMTD	.48
Wall Resistance, Rw	2.67
Overall H.T.C., Uo	1.14
Water-Side H.T.C., Hi	10.41
Vapor-Side H.T.C., Ho	7.38

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMANC1
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 100.024 (Deg C)
 Water Flow Rate (%) = 20.00
 Water Velocity = 1.16 (m/s)
 Heat Flux = 2.757E+05 (W/m²)
 Tube-metal thermal conduc. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0193

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.02
Reynolds Number, Re	3.14
Heat Flux, q	3.06
Log-Mean-Tem Diff, LMTD	.20
Wall Resistance, Rw	2.67
Overall H.T.C., Uo	3.06
Water-Side H.T.C., Hi	10.67
Vapor-Side H.T.C., Ho	27.24

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHC1
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 99.887 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 4.31 (m/s)
 Heat Flux = 4.952E+05 (W/m^2)
 Tube-metal thermal conduc. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0442

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.17
Heat Flux, q	1.01
Log-Mean-Tem Diff, LMTD	.41
Wall Resistance, Rw	2.67
Overall H.T.C., Uo	1.09
Water-Side H.T.C., Hi	4.64
Vapor-Side H.T.C., Ho	2.01

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHC1
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 99.879 (Deg C)
 Water Flow Rate (%) = 20.00
 Water Velocity = 1.15 (m/s)
 Heat Flux = 3.805E+05 (W/m^2)
 Tube-metal thermal conduc. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0442

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.03
Reynolds Number, Re	3.15
Heat Flux, q	3.06
Log-Mean-Tem Diff, LMTD	.14
Wall Resistance, Rw	2.67
Overall H.T.C., Uo	3.07
Water-Side H.T.C., Hi	5.20
Vapor-Side H.T.C., Ho	7.68

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMUNT3
 Pressure Condition: Vacuum
 Vapor Temperature = 48.670 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 3.63 (m/s)
 Heat Flux = 1.248E+05 (W/m^2)
 Tube-metal thermal conduc. = 21.0 (W/m.K)
 Sieder-Tate constant = 0.0179

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.12
Heat Flux, q	2.16
Log-Mean-Tem Diff, LMTD	1.95
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	2.91
Water-Side H.T.C., H1	16.79
Vapor-Side H.T.C., Ho	17.15

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMUNT3
 Pressure Condition: Vacuum
 Vapor Temperature = 48.736 (Deg C)
 Water Flow Rate (%) = 20.00
 Water Velocity = 0.97 (m/s)
 Heat Flux = 7.590E+04 (W/m^2)
 Tube-metal thermal conduc. = 21.0 (W/m.K)
 Sieder-Tate constant = 0.0179

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.01
Reynolds Number, Re	3.11
Heat Flux, q	3.16
Log-Mean-Tem Diff, LMTD	.86
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	3.28
Water-Side H.T.C., H1	16.95
Vapor-Side H.T.C., Ho	58.73

Heat Flux =
DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHT3
Pressure Condition: Vacuum
Vapor Temperature = 48.651 (Deg C)
Water Flow Rate (%) = 20.00
Water Velocity = 0.97 (m/s)
Heat Flux = 1.082E+05 (W/m^2)
Tube-metal thermal conduc. = 21.0 (W/m.K)
Sieder-Tate constant = 0.0431

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.01
Reynolds Number, Re	3.11
Heat Flux, q	3.10
Log-Mean-Tem Diff, LMTD	.60
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	3.16
Water-Side H.T.C., Hi	7.40
Vapor-Side H.T.C., Ho	12.54

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHT3
Pressure Condition: Vacuum
Vapor Temperature = 48.684 (Deg C)
Water Flow Rate (%) = 80.00
Water Velocity = 3.63 (m/s)
Heat Flux = 1.471E+05 (W/m^2)
Tube-metal thermal conduc. = 21.0 (W/m.K)
Sieder-Tate constant = 0.0431

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.12
Heat Flux, q	1.90
Log-Mean-Tem Diff, LMTD	1.66
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	2.52
Water-Side H.T.C., Hi	7.03
Vapor-Side H.T.C., Ho	6.07

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMANTS
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 100.026 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 3.63 (m/s)
 Heat Flux = 3.632E+05 (W/m^2)
 Tube-metal thermal conduc. = 21.0 (W/m.K)
 Sieder-Tate constant = 0.0191

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.14
Heat Flux, q	1.14
Log-Mean-Tem Diff, LMTD	.67
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	1.32
Water-Side H.T.C., H1	15.74
Vapor-Side H.T.C., Ho	11.68

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMANTS
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 99.958 (Deg C)
 Water Flow Rate (%) = 20.00
 Water Velocity = 0.97 (m/s)
 Heat Flux = 2.413E+05 (W/m^2)
 Tube-metal thermal conduc. = 21.0 (W/m.K)
 Sieder-Tate constant = 0.0191

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.02
Reynolds Number, Re	3.12
Heat Flux, q	3.06
Log-Mean-Tem Diff, LMTD	.27
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	3.07
Water-Side H.T.C., H1	15.91
Vapor-Side H.T.C., Ho	41.47

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHT6
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 100.020 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 3.62 (m/s)
 Heat Flux = 4.049E+05 (W/m^2)
 Tube-metal thermal conduc. = 21.0 (W/m.K)
 Sieder-Tate constant = 0.0403

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.15
Heat Flux, q	1.10
Log-Mean-Tem Diff, LMTD	.60
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	1.25
Water-Side H.T.C., H1	7.51
Vapor-Side H.T.C., Ho	4.13

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHT6
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 99.922 (Deg C)
 Water Flow Rate (%) = 20.00
 Water Velocity = 0.97 (m/s)
 Heat Flux = 3.120E+05 (W/m^2)
 Tube-metal thermal conduc. = 21.0 (W/m.K)
 Sieder-Tate constant = 0.0403

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.03
Reynolds Number, Re	3.15
Heat Flux, q	3.07
Log-Mean-Tem Diff, LMTD	.21
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	3.08
Water-Side H.T.C., H1	7.87
Vapor-Side H.T.C., Ho	11.47

APPENDIX D. DATA RUNS

The names of the data files are listed in Tables 2 through 13 in Chapter 5. The data files presented in this appendix have been reprocessed using the Petukhov-Popov [Ref. 29] form of the inside heat transfer correlation. The data have been printed out in the short form format.

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAHT1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.96 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.3715

Alpha (based on Nusselt (Tdel)) = 0.7801

Enhancement (q) = .983

Enhancement (Del-T) = .972

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tof (C)	Ts (C)
1	3.66	5.352E+03	9.727E+03	4.334E+05	44.55	100.11
2	3.21	5.297E+03	9.985E+03	4.242E+05	42.91	99.96
3	2.76	5.210E+03	1.003E+04	4.132E+05	41.19	99.97
4	2.31	5.054E+03	1.006E+04	3.969E+05	39.45	100.05
5	1.87	4.995E+03	1.030E+04	3.792E+05	36.81	100.01
6	1.42	4.639E+03	1.056E+04	3.546E+05	33.58	100.04
7	0.97	4.276E+03	1.128E+04	3.220E+05	28.55	100.07
8	1.42	4.619E+03	1.039E+04	3.486E+05	33.54	100.00
9	1.86	4.874E+03	1.011E+04	3.675E+05	36.35	99.94
10	2.30	5.091E+03	1.008E+04	3.845E+05	38.16	100.06
11	2.75	5.232E+03	9.967E+03	3.944E+05	39.67	99.99
12	3.19	5.335E+03	9.960E+03	4.014E+05	40.71	99.95
13	3.63	5.391E+03	9.692E+03	4.055E+05	41.84	100.05

Least-Squares Line for Ho vs q curve:

Slope = -3.1043E-01

Intercept = 7.7997E+05

Least-squares line for q = a+delta-T^{1/4}b

a = 2.5179E+04

b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT1

NOTE: 13 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAHT2
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.66 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for h_o

C_1 (based on Petukhov-Popov) = 2.3833
 Alpha (based on Nusselt (T_{del})) = 0.7740
 Enhancement (q) = .953
 Enhancement ($Q_{el}-T$) = .965

Data #	V_w (m/s)	U_o (W/m ² -K)	h_o (W/m ² -K)	Q_p (W/m ²)	T_{of} (C)	T_s (C)
1	3.65	5.332E+03	9.587E+03	4.209E+05	43.91	100.00
2	3.20	5.312E+03	9.853E+03	4.147E+05	42.08	99.94
3	2.75	5.197E+03	9.887E+03	4.018E+05	40.54	100.00
4	2.31	5.068E+03	1.000E+04	3.875E+05	38.74	100.00
5	1.42	4.657E+03	1.049E+04	3.474E+05	33.12	100.02
6	0.97	4.280E+03	1.109E+04	3.150E+05	29.40	99.99
7	1.41	4.675E+03	1.054E+04	3.459E+05	32.83	100.20
8	1.86	4.940E+03	1.029E+04	3.655E+05	35.51	99.98
9	2.30	5.114E+03	1.008E+04	3.785E+05	37.54	100.00
10	2.74	5.245E+03	9.944E+03	3.882E+05	39.04	100.00
11	3.18	5.329E+03	9.763E+03	3.939E+05	40.26	100.00
12	3.62	5.456E+03	9.657E+03	4.022E+05	40.80	99.99
13	3.62	5.448E+03	9.823E+03	4.006E+05	40.76	99.94

Least-Squares Line for h_o vs q curve:

Slope = -3.1763E-01

Intercept = 7.2191E-05

Least-squares line for $q = a + \Delta T^b$

a = 2.4999E+04

b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT2

NOTE: 13 ΔT pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAHT3
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.96 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.3923
 Alpha (based on Nusselt (Tdel)) = 0.7551
 Enhancement (q) = .922
 Enhancement (Del-T) = .941

Data #	Vw (m/s)	Uc (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tef (C)	Ts (C)
1	3.62	5.411E+03	9.701E+03	4.000E+05	41.23	99.93
2	3.18	5.316E+03	9.717E+03	3.913E+05	40.27	100.01
3	2.74	5.185E+03	9.693E+03	3.796E+05	39.16	100.02
4	2.29	5.048E+03	9.766E+03	3.674E+05	37.63	100.05
5	1.85	4.872E+03	9.904E+03	3.520E+05	35.54	99.93
6	1.41	4.633E+03	1.017E+04	3.322E+05	32.68	99.95
7	1.19	4.494E+03	1.050E+04	3.205E+05	30.53	100.00
8	0.97	4.322E+03	1.105E+04	3.063E+05	27.72	100.08

Least-Squares Line for Ho vs q curve:
 Slope = -3.1603E-01
 Intercept = 7.7848E+05

Least-squares line for q = a+delta-T*b
 a = 2.4500E+04
 b = 7.5000E-01

NOTE: 08 data points were stored in file FONMAHT3

NOTE: 08 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAHT4
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.96 (mm)
 Outside diameter, Do = 15.95 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.4099
 Alpha (based on Nusselt (Tdel)) = 0.7484
 Enhancement (q) = .911
 Enhancement (Del-T) = .933

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tof (C)	Ts (C)
1	0.97	4.236E+03	1.079E+04	3.171E+05	29.40	100.04
2	1.42	4.556E+03	9.950E+03	3.427E+05	31.41	100.03
3	1.64	4.702E+03	9.843E+03	3.517E+05	35.74	99.99
4	2.08	4.919E+03	9.698E+03	3.678E+05	37.92	99.98
5	2.52	5.108E+03	9.703E+03	3.809E+05	39.26	100.03
6	2.96	5.221E+03	9.537E+03	3.881E+05	40.41	100.04
7	3.40	5.329E+03	9.570E+03	3.936E+05	41.13	99.99
8	3.62	5.358E+03	9.505E+03	3.946E+05	41.52	100.02
9	3.18	5.295E+03	9.612E+03	3.874E+05	40.30	100.10
10	2.73	5.136E+03	9.657E+03	3.774E+05	39.07	100.03
11	2.29	5.010E+03	9.583E+03	3.627E+05	37.85	100.20
12	1.63	4.739E+03	9.650E+03	3.398E+05	34.50	100.02
13	0.97	4.266E+03	1.070E+04	3.025E+05	29.21	100.03

Least-Squares Line for Ho vs q curve:

Slope = -3.1839E-01

Intercept = 7.7609E+05

Least-squares line for q = a*delta-T^{1/4}

a = 2.4222E+04

b = 7.5000E-01

NOTE: 12 data points were stored in file FONMAHT4

NOTE: 13 4-7 pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAHTS
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.36 (mm)
 Outside diameter, Do = 15.35 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.2011
 Alpha (based on Nusselt (Tdel)) = 0.7700
 Enhancement (q) = .947
 Enhancement (Del-T) = .960

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tof (C)	Ts (C)
1	3.64	5.268E+03	9.574E+03	4.057E+05	42.38	99.90
2	3.19	5.273E+03	9.935E+03	4.002E+05	40.23	99.96
3	2.74	5.200E+03	1.014E+04	3.896E+05	38.41	99.95
4	2.30	5.035E+03	1.015E+04	3.717E+05	36.62	99.92
5	1.85	4.822E+03	1.018E+04	3.509E+05	34.47	100.00
6	1.41	4.599E+03	1.064E+04	3.313E+05	31.14	99.99
7	0.97	4.218E+03	1.132E+04	2.994E+05	26.44	100.05
8	1.19	4.423E+03	1.034E+04	3.152E+05	29.08	99.97
9	1.63	4.770E+03	1.058E+04	3.428E+05	32.40	100.02
10	2.07	4.992E+03	1.034E+04	3.595E+05	34.77	99.93
11	2.51	5.159E+03	1.020E+04	3.730E+05	36.56	100.02
12	2.95	5.253E+03	9.979E+03	3.900E+05	38.06	99.92
13	3.39	5.303E+03	9.632E+03	3.862E+05	39.26	99.96
14	3.61	5.394E+03	9.660E+03	3.908E+05	39.63	100.27

Least-Squares Line for Ho vs q curve:

Slope = -3.1391E-01

Intercept = 7.7964E+05

Least-squares line for q = a+delta-T*b

a = 2.4990E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHTS

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAHTS

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.96 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.5406

Alpha (based on Nusselt (Tdel)) = 0.7758

Enhancement (q) = .956

Enhancement (Del-T) = .967

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tof (C)	Ta (C)
1	3.62	5.523E+03	9.871E+03	4.049E+05	41.01	100.02
2	3.18	5.441E+03	9.803E+03	3.969E+05	40.00	100.05
3	2.73	5.369E+03	1.010E+04	3.882E+05	38.54	99.99
4	2.29	5.247E+03	1.023E+04	3.765E+05	36.91	99.90
5	2.07	5.133E+03	1.016E+04	3.680E+05	36.21	99.98
6	1.41	4.826E+03	1.064E+04	3.410E+05	32.06	99.79
7	0.97	4.458E+03	1.101E+04	3.120E+05	27.93	99.92
8	1.41	4.816E+03	1.053E+04	3.411E+05	32.00	99.92
9	1.95	5.089E+03	1.044E+04	3.630E+05	34.76	99.99
10	2.29	5.230E+03	1.015E+04	3.744E+05	35.99	99.98
11	2.51	5.320E+03	1.017E+04	3.806E+05	37.44	99.94
12	2.73	5.411E+03	1.022E+04	3.876E+05	37.93	99.97
13	3.17	5.461E+03	9.960E+03	3.920E+05	39.36	100.04

Least-Squares Line for Ho vs q curve:

Slope = -3.0354E-01

Intercept = 7.7703E+05

Least-squares line for q = a+delta-T/b

a = 2.6178E+04

b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHTS

NOTE: 13 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAHT7
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.65 (mm)
 Outside diameter, Do = 15.65 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.5109
 Alpha (based on Nusselt (Tdel)) = 0.7924
 Enhancement (q) = .983
 Enhancement (Del-T) = .987

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tof (C)	Ts (C)
1	3.64	5.512E+03	9.985E+03	4.286E+05	42.93	100.05
2	3.19	5.415E+03	9.976E+03	4.142E+05	41.62	99.94
3	2.75	5.348E+03	1.018E+04	4.048E+05	39.79	99.90
4	2.52	5.309E+03	1.030E+04	3.998E+05	38.81	100.03
5	2.30	5.239E+03	1.037E+04	3.923E+05	37.94	99.94
6	2.08	5.150E+03	1.041E+04	3.847E+05	36.94	100.05
7	1.86	5.037E+03	1.043E+04	3.742E+05	35.97	99.91
8	1.41	4.791E+03	1.073E+04	3.538E+05	32.97	99.96
9	0.97	4.451E+03	1.157E+04	3.252E+05	29.10	100.06
10	1.41	4.799E+03	1.078E+04	3.551E+05	32.95	100.04
11	1.86	5.042E+03	1.045E+04	3.752E+05	35.99	100.03
12	2.30	5.231E+03	1.032E+04	3.696E+05	37.76	99.93
13	2.74	5.372E+03	1.022E+04	4.007E+05	39.20	99.93

Least-Squares Line for Ho vs q curve:
 Slope = -3.1602E-01
 Intercept = 7.8428E+05

Least-squares line for q = a*delta-T b
 a = 2.5669E+04
 b = 7.9000E-01

NOTE: 13 data points were stored in file FONMAHT7

NOTE: 13 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMANT1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.2114
 Alpha (based on Nusselt (Tdel)) = 0.7504
 Enhancement (q) = .941
 Enhancement (Del-T) = .955

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tof (C)	Ts (C)
1	2.74	4.483E+03	1.050E+04	3.315E+05	31.56	100.02
2	2.51	4.389E+03	1.053E+04	3.200E+05	30.39	99.99
3	2.29	4.273E+03	1.051E+04	3.091E+05	29.42	100.05
4	2.07	4.147E+03	1.052E+04	2.971E+05	28.25	99.99
5	1.85	4.006E+03	1.056E+04	2.851E+05	26.95	99.90
6	1.41	3.687E+03	1.106E+04	2.609E+05	23.60	99.99
7	0.97	3.283E+03	1.293E+04	2.304E+05	17.91	99.96
8	1.41	3.687E+03	1.101E+04	2.594E+05	23.57	99.99
9	1.85	4.030E+03	1.066E+04	2.837E+05	26.60	99.95
10	2.07	4.183E+03	1.064E+04	2.949E+05	27.72	100.18
11	2.30	4.295E+03	1.076E+04	3.161E+05	29.36	99.91
12	2.74	4.450E+03	1.042E+04	3.356E+05	32.21	100.23
13	3.19	4.623E+03	1.037E+04	3.499E+05	33.71	99.89

Least-Squares Line for Ho vs q curve:

Slope = -2.6012E-01
 Intercept = 7.6036E+05

Least-squares line for q = a*delta-T b

a = 2.4594E-04
 b = 7.5000E-01

NOTE: 13 data points were stored in file FONMANT1

NOTE: 13 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMANT2

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.85 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

Di (based on Petukhov-Popov) = 1.1849

Alpha (based on Nusselt (Tdel)) = 0.7503

Enhancement (q) = .957

Enhancement (Del-T) = .968

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.65	4.669E+03	1.022E+04	3.713E+05	36.34	99.99
2	3.20	4.572E+03	1.046E+04	3.566E+05	34.28	100.01
3	2.75	4.426E+03	1.064E+04	3.421E+05	32.15	100.01
4	2.31	4.226E+03	1.080E+04	3.226E+05	29.86	100.04
5	1.86	3.933E+03	1.073E+04	2.958E+05	27.57	99.94
6	1.41	3.616E+03	1.127E+04	2.636E+05	23.34	100.00
7	0.97	3.263E+03	1.396E+04	2.392E+05	17.06	99.99
8	1.19	3.387E+03	1.118E+04	2.454E+05	21.95	99.95
9	0.97	3.209E+03	1.261E+04	2.286E+05	18.15	99.93
10	1.19	3.399E+03	1.112E+04	2.424E+05	21.80	99.99
11	1.41	3.647E+03	1.115E+04	2.608E+05	23.39	99.99
12	1.86	4.000E+03	1.065E+04	2.868E+05	26.43	99.91
13	2.07	4.154E+03	1.092E+04	2.988E+05	27.62	100.11
14	2.29	4.286E+03	1.079E+04	3.082E+05	28.67	99.98
15	2.51	4.410E+03	1.077E+04	3.167E+05	29.40	99.97
16	2.73	4.530E+03	1.081E+04	3.248E+05	30.04	99.91

Least-Squares Line for Ho vs q curve:

Slope = -2.5701E-01

Intercept = 7.5050E-05

Least-squares line for q = a*delta-T^{1/4}b

a = 2.5129E+04

b = 7.3000E-01

NOTE: 16 data points were stored in file FONMANT2

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMANT3
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.96 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.1636
 Alpha (based on Nusselt (Tof)) = 0.7650
 Enhancement (q) = .965
 Enhancement (Del-T) = .974

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tof (C)	Ts (C)
1	0.97	3.230E+03	1.310E+04	2.269E+05	17.32	99.88
2	1.41	3.652E+03	1.136E+04	2.595E+05	22.66	100.05
3	1.63	3.837E+03	1.113E+04	2.730E+05	24.53	99.92
4	1.85	4.008E+03	1.104E+04	2.857E+05	25.89	99.97
5	2.07	4.143E+03	1.087E+04	2.959E+05	27.21	99.96
6	2.29	4.236E+03	1.057E+04	3.028E+05	28.64	99.93
7	2.51	4.424E+03	1.096E+04	3.165E+05	29.67	99.99
8	2.73	4.513E+03	1.082E+04	3.229E+05	29.83	99.92
9	2.95	4.627E+03	1.088E+04	3.308E+05	30.41	99.92
10	3.17	4.745E+03	1.101E+04	3.394E+05	30.92	99.94
11	3.61	4.815E+03	1.055E+04	3.457E+05	32.76	100.01
12	2.29	4.291E+03	1.092E+04	3.070E+05	26.12	100.04

Least-Squares Line for Ho vs q curve:
 Slope = -2.4792E-01
 Intercept = 7.5635E+05

Least-squares line for q = a*delta-T b
 a = 2.5250E-04
 b = 7.5000E-01

NOTE: 12 data points were stored in file FONMANT3

NOTE: 12 x-y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMANT4

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for h_o

C_1 (based on Petukhov-Popov) = 1.1611

Alpha (based on Nusselt (T_{del})) = 0.7648

Enhancement (q) = .985

Enhancement ($Del-T$) = .974

Data #	V_w (m/s)	U_o (W/m ² -K)	h_o (W/m ² -K)	Q_p (W/m ²)	T_{of} (C)	T_s (C)
1	3.62	4.778E+03	1.036E+04	3.479E+05	33.59	100.00
2	0.97	3.192E+03	1.259E+04	2.299E+05	16.26	100.06
3	1.85	3.969E+03	1.083E+04	2.910E+05	26.87	99.97
4	2.30	4.246E+03	1.072E+04	3.133E+05	29.23	100.02
5	2.74	4.465E+03	1.064E+04	3.317E+05	31.19	100.21
6	3.12	4.648E+03	1.059E+04	3.453E+05	32.58	99.99
7	3.63	4.792E+03	1.047E+04	3.552E+05	33.99	99.96
8	3.62	4.755E+03	1.030E+04	3.525E+05	34.21	100.34
9	3.18	4.663E+03	1.061E+04	3.433E+05	32.36	100.24
10	2.74	4.506E+03	1.079E+04	3.294E+05	30.62	99.99
11	2.29	4.267E+03	1.077E+04	3.110E+05	28.88	100.01
12	1.85	3.971E+03	1.077E+04	2.895E+05	26.99	100.29
13	1.41	3.629E+03	1.116E+04	2.626E+05	23.54	99.90
14	0.97	3.193E+03	1.266E+04	2.305E+05	16.21	99.99

Least-Squares Line for h_o vs q curve:

Slope = -2.5738E-01

Intercept = 7.6096E+05

Least-squares line for $q = a + \Delta T \cdot b$

a = 2.5144E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANT4

NOTE: 14 X-y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMANTS
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.96 (mm)
 Outside diameter, Do = 15.65 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.2370
 Alpha (based on Nusselt (Tdel)) = 0.7863
 Enhancement (q) = 1.001
 Enhancement (Del-T) = 1.001

Data #	Uw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tof (C)	Ts (C)
1	3.63	4.877E+03	1.061E+04	3.632E+05	34.25	100.03
2	3.18	4.755E+03	1.076E+04	3.513E+05	32.64	99.97
3	2.74	4.591E+03	1.093E+04	3.394E+05	31.06	100.00
4	2.30	4.374E+03	1.107E+04	3.234E+05	29.22	100.00
5	1.86	4.083E+03	1.115E+04	3.021E+05	27.09	100.02
6	1.41	3.723E+03	1.148E+04	2.750E+05	23.95	100.00
7	0.97	3.267E+03	1.309E+04	2.413E+05	18.43	99.96
8	1.41	3.720E+03	1.148E+04	2.755E+05	23.99	99.97
9	0.97	3.263E+03	1.308E+04	2.416E+05	18.47	99.95
10	1.86	4.081E+03	1.120E+04	3.040E+05	27.15	100.01
11	2.30	4.390E+03	1.117E+04	3.267E+05	29.26	99.99
12	2.74	4.572E+03	1.091E+04	3.436E+05	31.49	100.04
13	3.18	4.748E+03	1.081E+04	3.573E+05	33.04	100.05
14	3.63	4.873E+03	1.064E+04	3.664E+05	34.45	99.96
15	2.30	4.355E+03	1.103E+04	3.263E+05	29.57	100.00
16	0.97	3.256E+03	1.278E+04	2.411E+05	18.86	99.94

Least-Squares Line for Ho vs q curve:
 Slope = -2.5021E-01
 Intercept = 7.6397E+05

Least-squares line for q = a*delta-T^b
 a = 2.5924E+04
 b = 7.5000E-01

NOTE: 16 data points were stored in file FONMANTS

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVHT3

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.66 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.5472

Alpha (based on Nusselt (Tdel)) = 0.7483

Enhancement (q) = .624

Enhancement (Del-T) = .665

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	0.97	4.574E+03	1.251E+04	1.082E+05	8.65	48.65
2	1.64	5.049E+03	1.115E+04	1.231E+05	11.04	48.64
3	2.08	5.282E+03	1.096E+04	1.303E+05	11.89	48.68
4	2.52	5.490E+03	1.098E+04	1.362E+05	12.40	48.67
5	2.97	5.652E+03	1.099E+04	1.407E+05	12.80	48.67
6	3.41	5.797E+03	1.106E+04	1.446E+05	13.08	48.65
7	3.63	5.871E+03	1.113E+04	1.471E+05	13.22	48.66
8	3.63	5.815E+03	1.093E+04	1.457E+05	13.33	48.70
9	3.41	5.774E+03	1.098E+04	1.445E+05	13.16	48.72
10	2.97	5.690E+03	1.114E+04	1.412E+05	12.67	48.63
11	2.08	5.275E+03	1.092E+04	1.297E+05	11.87	48.67
12	1.64	5.052E+03	1.116E+04	1.232E+05	11.04	48.70
13	1.19	4.698E+03	1.142E+04	1.130E+05	9.99	48.69
14	0.97	4.474E+03	1.130E+04	1.060E+05	9.99	48.62

Least-Squares Line for Ho vs q curve:

Slope = -3.1158E-01

Intercept = 5.6173E+05

Least-squares line for q = a*delta-T^{1.5}

a = 2.0703E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHT3

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVHT4

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, D_i = 13.86 (mm)

Outside diameter, D_o = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for h_o

C_1 (based on Petukhov-Popov) = 2.2780

α (based on Nusselt (T_{del})) = 0.7900

Enhancement (q) = .985

Enhancement (ΔT) = .913

Data #	V_w (m/s)	U_o (W/m ² -K)	h_o (W/m ² -K)	q_p (W/m ²)	T_{cf} (C)	T_s (C)
1	3.64	5.867E+03	1.159E+04	1.505E+05	12.98	48.68
2	3.19	5.759E+03	1.167E+04	1.456E+05	12.48	48.65
3	2.75	5.583E+03	1.158E+04	1.392E+05	12.01	48.63
4	2.52	5.559E+03	1.169E+04	1.380E+05	11.60	48.67
5	2.30	5.421E+03	1.175E+04	1.339E+05	11.39	48.68
6	2.08	5.280E+03	1.165E+04	1.299E+05	11.14	48.67
7	1.86	5.203E+03	1.198E+04	1.273E+05	10.62	48.64
8	1.42	4.908E+03	1.242E+04	1.192E+05	9.59	48.70
9	0.97	4.453E+03	1.326E+04	1.066E+05	8.04	48.74
10	1.42	4.907E+03	1.243E+04	1.196E+05	9.62	48.65
11	1.86	5.161E+03	1.178E+04	1.274E+05	10.82	48.67
12	2.30	5.424E+03	1.178E+04	1.350E+05	11.46	48.68
13	2.53	5.530E+03	1.177E+04	1.380E+05	11.73	48.69
14	2.75	5.607E+03	1.169E+04	1.403E+05	12.01	48.74
15	3.19	5.731E+03	1.154E+04	1.435E+05	12.43	48.66
16	3.63	5.831E+03	1.143E+04	1.464E+05	12.81	48.68

Least-Squares Line for h_o vs q curve:

Slope = -3.2707E-01

Intercept = 5.8591E+05

Least-squares line for $q = a \cdot \Delta T^b$

a = 2.1743E+04

b = 7.5000E-01

NOTE: 16 data points were stored in file FONMVHT4

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMUHTS
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4221
 Alpha (based on Nusselt (Tdel)) = 0.7627
 Enhancement (q) = .845
 Enhancement (Del-T) = .881

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	0.97	4.402E+03	1.202E+04	1.082E+05	9.00	48.67
2	1.42	4.872E+03	1.165E+04	1.215E+05	10.43	48.64
3	1.86	5.173E+03	1.141E+04	1.301E+05	11.41	48.65
4	2.08	5.274E+03	1.125E+04	1.331E+05	11.83	48.72
5	2.30	5.395E+03	1.128E+04	1.362E+05	12.07	48.70
6	2.53	5.422E+03	1.097E+04	1.366E+05	12.45	48.65
7	2.75	5.510E+03	1.098E+04	1.395E+05	12.71	48.75
8	3.19	5.676E+03	1.105E+04	1.440E+05	13.02	48.78
9	3.64	5.745E+03	1.087E+04	1.461E+05	13.44	48.78
10	3.19	5.741E+03	1.130E+04	1.453E+05	12.86	48.82
11	2.75	5.600E+03	1.133E+04	1.404E+05	12.39	48.69
12	2.30	5.390E+03	1.124E+04	1.347E+05	11.96	48.73
13	2.08	5.317E+03	1.143E+04	1.324E+05	11.59	48.72
14	1.86	5.202E+03	1.152E+04	1.296E+05	11.24	48.80
15	1.42	4.874E+03	1.162E+04	1.198E+05	10.31	48.74

Least-Squares Line for Ho vs q curve:

Slope = -3.1155E-01

Intercept = 5.8244E+05

Least-squares line for q = a*delta-T^b

a = 2.0955E+04

b = 7.5000E-01

NOTE: 15 data points were stored in file FONMUHTS

NOTE: 15 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMUNT2
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0922
 Alpha (based on Nusselt (Tdel)) = 0.8215
 Enhancement (q) = .878
 Enhancement (Del-T) = .907

Data #	Uw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.038E+03	1.269E+04	1.244E+05	9.81	48.66
2	3.19	4.901E+03	1.307E+04	1.206E+05	9.23	48.70
3	2.74	4.702E+03	1.334E+04	1.155E+05	8.66	48.76
4	2.52	4.581E+03	1.346E+04	1.122E+05	8.34	48.74
5	2.30	4.450E+03	1.363E+04	1.089E+05	7.99	48.77
6	2.08	4.267E+03	1.348E+04	1.045E+05	7.75	48.82
7	1.86	4.081E+03	1.353E+04	1.003E+05	7.41	48.65
8	1.42	3.698E+03	1.447E+04	9.028E+04	6.24	48.65
9	0.97	3.076E+03	1.429E+04	7.465E+04	5.23	48.70
10	1.86	4.119E+03	1.396E+04	1.015E+05	7.27	48.70
11	2.75	4.739E+03	1.367E+04	1.178E+05	8.61	48.79
12	3.63	5.059E+03	1.283E+04	1.258E+05	9.61	48.74

Least-Squares Line for Ho vs q curve:
 Slope = -2.5424E-01
 Intercept = 5.7915E+05

Least-squares line for q = a*delta-T^b
 a = 2.2680E+04
 b = 7.5000E-01

NOTE: 12 data points were stored in file FONMUNT2

NOTE: 12 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMUNT3

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.0775

Alpha (based on Nusselt (Tdel)) = 0.7976

Enhancement (q) = .630

Enhancement (Del-T) = .869

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	4.954E+03	1.235E+04	1.248E+05	10.11	48.67
2	3.19	4.794E+03	1.255E+04	1.204E+05	9.59	48.64
3	2.75	4.586E+03	1.271E+04	1.152E+05	9.07	48.66
4	2.30	4.325E+03	1.284E+04	1.086E+05	8.46	48.73
5	1.86	3.990E+03	1.291E+04	9.969E+04	7.72	48.70
6	1.42	3.629E+03	1.394E+04	8.986E+04	6.45	48.63
7	0.97	3.079E+03	1.508E+04	7.590E+04	5.03	48.74
8	1.42	3.643E+03	1.416E+04	9.041E+04	6.39	48.62
9	0.97	3.061E+03	1.464E+04	7.506E+04	5.13	48.63
10	2.30	4.305E+03	1.268E+04	1.080E+05	8.51	48.60
11	2.75	4.555E+03	1.248E+04	1.146E+05	9.18	48.67
12	3.19	4.767E+03	1.237E+04	1.200E+05	9.70	48.69
13	3.63	4.946E+03	1.229E+04	1.245E+05	10.13	48.73
14	3.19	4.768E+03	1.237E+04	1.193E+05	9.65	48.67
15	3.63	4.977E+03	1.248E+04	1.248E+05	10.00	48.71
16	2.75	4.568E+03	1.255E+04	1.140E+05	9.09	48.73
17	2.30	4.322E+03	1.278E+04	1.072E+05	8.36	48.63
18	1.86	3.981E+03	1.278E+04	9.859E+04	7.72	48.71
19	1.42	3.636E+03	1.397E+04	8.922E+04	6.39	48.67
20	0.97	3.062E+03	1.455E+04	7.448E+04	5.12	48.70

Least-Squares Line for Ho vs q curve:

Slope = -2.8863E-01

Intercept = 5.3155E+05

Least-squares line for q = a*delta-T^b

a = 2.1947E+04

b = 7.5000E-01

NOTE: 20 data points were stored in file FONMUNT3

NOTE: 20 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMUNT4

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.85 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 1.0742

Alpha (based on Nusselt (T_{del})) = 0.8455

Enhancement (q) = .912

Enhancement (Δ_l-T) = .933

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.095E+03	1.328E+04	1.274E+05	9.59	48.68
2	3.19	4.910E+03	1.340E+04	1.222E+05	9.12	48.63
3	2.75	4.749E+03	1.407E+04	1.183E+05	8.41	48.66
4	2.30	4.459E+03	1.413E+04	1.110E+05	7.86	48.66
5	1.86	4.166E+03	1.502E+04	1.037E+05	6.91	48.70
6	1.42	3.726E+03	1.559E+04	9.234E+04	5.92	48.67
7	0.97	3.166E+03	1.764E+04	7.792E+04	4.42	48.72
8	1.42	3.719E+03	1.550E+04	9.256E+04	5.97	48.67
9	0.97	3.161E+03	1.747E+04	7.765E+04	4.45	48.65
10	1.86	4.133E+03	1.464E+04	1.037E+05	7.03	48.70
11	2.30	4.476E+03	1.435E+04	1.125E+05	7.84	48.72
12	2.75	4.699E+03	1.366E+04	1.180E+05	8.63	48.68
13	3.19	4.914E+03	1.345E+04	1.234E+05	9.13	48.63
14	3.63	5.100E+03	1.333E+04	1.279E+05	9.60	48.65

Least-Squares Line for Ho vs q curve:

Slope = -2.9438E-01

Intercept = 5.8472E+05

Least-squares line for q = a*Δ_l-T^b

a = 2.4011E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMUNT4

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMUNT5

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.1127

Alpha (based on Nusselt (Tdel)) = 0.8274

Enhancement (q) = .836

Enhancement (Del-T) = .913

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.64	5.029E+03	1.251E+04	1.299E+05	10.30	48.70
2	3.19	4.895E+03	1.291E+04	1.255E+05	9.72	48.73
3	2.75	4.735E+03	1.346E+04	1.209E+05	8.98	48.68
4	2.31	4.454E+03	1.353E+04	1.143E+05	8.45	48.73
5	1.86	4.116E+03	1.371E+04	1.054E+05	7.69	48.67
6	1.42	3.746E+03	1.490E+04	9.534E+04	6.40	48.68
7	0.97	3.180E+03	1.629E+04	7.999E+04	4.91	48.64
8	1.42	3.742E+03	1.490E+04	9.590E+04	6.44	48.70
9	0.97	3.180E+03	1.631E+04	8.016E+04	4.92	48.64
10	1.86	4.146E+03	1.408E+04	1.071E+05	7.60	48.71
11	2.31	4.489E+03	1.389E+04	1.159E+05	8.34	48.65
12	2.75	4.705E+03	1.327E+04	1.220E+05	9.19	48.72
13	3.19	4.894E+03	1.293E+04	1.266E+05	9.79	48.68
14	3.64	5.053E+03	1.259E+04	1.307E+05	10.30	48.64
15	2.31	4.487E+03	1.386E+04	1.151E+05	8.31	48.62
16	0.97	3.194E+03	1.662E+04	8.039E+04	4.94	48.76
17	3.64	5.059E+03	1.274E+04	1.312E+05	10.30	48.63

Least-Squares Line for Ho vs q curve:

Slope = -3.0266E-01

Intercept = 5.8489E+05

Least-squares line for q = a*delta-T^b

a = 2.3349E+04

b = 7.5000E-01

NOTE: 17 data points were stored in file FONMUNT5

NOTE: 17 K-T pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAH1T1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.0225
 Alpha (based on Nusselt (T_{del})) = 0.7981
 Enhancement (q) = 1.047
 Enhancement (Δ_l-T) = 1.035

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.62	5.446E+03	1.036E+04	3.995E+05	38.45	99.98
2	3.18	5.361E+03	1.049E+04	3.996E+05	37.14	99.95
3	2.73	5.268E+03	1.071E+04	3.914E+05	35.61	100.01
4	2.29	5.071E+03	1.069E+04	3.654E+05	34.13	99.93
5	1.85	4.858E+03	1.087E+04	3.496E+05	32.17	100.01
6	1.41	4.568E+03	1.119E+04	3.269E+05	29.22	99.89
7	0.97	4.150E+03	1.200E+04	2.957E+05	24.53	99.94
8	1.41	4.565E+03	1.119E+04	3.273E+05	29.29	99.95
9	0.97	4.147E+03	1.197E+04	2.955E+05	24.68	99.99
10	1.85	4.863E+03	1.090E+04	3.513E+05	32.21	100.05
11	2.29	5.073E+03	1.070E+04	3.670E+05	34.29	100.05
12	2.73	5.252E+03	1.069E+04	3.905E+05	35.60	99.97
13	3.17	5.373E+03	1.052E+04	3.899E+05	36.96	99.99
14	3.61	5.467E+03	1.041E+04	3.958E+05	39.00	100.02

Least-Squares Line for Ho vs q curves

Slope = -2.8216E-01
 Intercept = 7.7250E+05

Least-squares line for q = a*Δ_l-T_{fb}

a = 2.6057E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH1T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAN1T1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 1.1307
 Alpha (based on Nusselt (T_{del})) = 0.7825
 Enhancement (q) = 1.030
 Enhancement (Δ_{el}-T) = 1.022

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	T _{of} (C)	T _s (C)
1	3.61	4.807E+03	1.077E+04	3.467E+05	32.19	99.91
2	3.17	4.688E+03	1.104E+04	3.395E+05	30.76	99.99
3	2.73	4.497E+03	1.111E+04	3.257E+05	29.32	99.97
4	2.29	4.284E+03	1.133E+04	3.101E+05	27.36	99.93
5	1.85	3.979E+03	1.140E+04	2.883E+05	25.30	99.95
6	1.41	3.606E+03	1.170E+04	2.607E+05	22.28	99.95
7	0.97	3.138E+03	1.305E+04	2.259E+05	17.31	99.93
8	1.41	3.597E+03	1.165E+04	2.614E+05	22.43	99.99
9	0.97	3.150E+03	1.329E+04	2.272E+05	17.09	99.94
10	1.85	3.970E+03	1.141E+04	2.903E+05	25.44	99.93
11	2.29	4.261E+03	1.126E+04	3.122E+05	27.73	100.01
12	2.74	4.491E+03	1.115E+04	3.296E+05	29.55	99.99
13	3.18	4.650E+03	1.090E+04	3.412E+05	31.31	99.99
14	3.62	4.789E+03	1.075E+04	3.516E+05	32.71	100.05

Least-Squares Line for Ho vs q curve:

Slope = -2.4626E-01

Intercept = 7.5014E+05

Least-squares line for q = a*delta-T b

a = 2.5679E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN1T1

NOTE: 14 x-y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVH1T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.9918

Alpha (based on Nusselt (Tdel)) = 0.8018

Enhancement (q) = 1.061

Enhancement (Del-T) = 1.045

Data #	Uw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.745E+03	1.196E+04	1.383E+05	11.56	48.65
2	3.19	5.661E+03	1.225E+04	1.364E+05	11.14	48.72
3	2.74	5.516E+03	1.244E+04	1.321E+05	10.62	48.65
4	2.30	5.291E+03	1.248E+04	1.269E+05	10.18	48.74
5	1.86	5.007E+03	1.256E+04	1.192E+05	9.49	48.65
6	1.41	4.660E+03	1.297E+04	1.105E+05	8.52	48.72
7	0.97	4.147E+03	1.379E+04	9.748E+04	7.07	48.68
8	1.41	4.655E+03	1.295E+04	1.107E+05	8.55	48.65
9	0.97	4.161E+03	1.396E+04	9.767E+04	6.99	48.59
10	1.86	5.005E+03	1.257E+04	1.203E+05	9.58	48.69
11	2.30	5.254E+03	1.228E+04	1.266E+05	10.31	48.73
12	2.74	5.500E+03	1.236E+04	1.321E+05	10.68	48.71
13	3.19	5.641E+03	1.215E+04	1.352E+05	11.13	48.69
14	3.63	5.740E+03	1.192E+04	1.365E+05	11.45	48.66

Least-Squares Line for Ho vs q curve:

Slope = -3.0415E-01

Intercept = 5.8381E+05

Least-squares line for q = a*delta-T^b

a = 2.2233E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH1T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVN1T1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 1.0235
 Alpha (based on Nusselt (T_{del})) = 0.8381
 Enhancement (q) = 1.029
 Enhancement (Del-T) = 1.021

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.036E+03	1.333E+04	1.191E+05	8.93	48.64
2	3.18	4.903E+03	1.395E+04	1.147E+05	8.29	48.70
3	2.74	4.718E+03	1.437E+04	1.093E+05	7.61	48.74
4	2.30	4.410E+03	1.427E+04	1.012E+05	7.09	48.71
5	1.85	4.088E+03	1.479E+04	9.300E+04	6.29	48.71
6	1.41	3.653E+03	1.550E+04	8.244E+04	5.32	48.68
7	0.97	3.071E+03	1.645E+04	6.840E+04	4.16	48.68
8	1.41	3.655E+03	1.542E+04	8.279E+04	5.37	48.68
9	0.97	3.074E+03	1.852E+04	6.840E+04	4.14	48.65
10	1.85	4.083E+03	1.475E+04	9.302E+04	6.31	48.63
11	2.30	4.405E+03	1.422E+04	1.012E+05	7.11	48.67
12	2.74	4.729E+03	1.444E+04	1.084E+05	7.50	48.65
13	3.18	4.906E+03	1.381E+04	1.125E+05	8.14	48.70
14	3.62	5.058E+03	1.340E+04	1.160E+05	8.66	48.72

Least-Squares Line for Ho vs q curve:

Slope = -2.5701E-01
 Intercept = 5.3022E+05

Least-squares line for q = a*delta-T^b

a = 2.3429E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN1T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAH2T3

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.96 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.4479

Alpha (based on Nusselt (Tdel)) = 0.8064

Enhancement (q) = 1.062

Enhancement (Del-T) = 1.046

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.50	5.719E+03	1.054E+04	3.982E+05	37.78	99.95
2	3.16	5.593E+03	1.047E+04	3.876E+05	37.02	99.99
3	2.72	5.523E+03	1.072E+04	3.857E+05	35.98	100.00
4	2.28	5.382E+03	1.086E+04	3.767E+05	34.70	100.03
5	1.85	5.151E+03	1.087E+04	3.612E+05	33.23	100.01
6	1.41	4.995E+03	1.121E+04	3.426E+05	30.58	100.00
7	0.97	4.499E+03	1.186E+04	3.130E+05	26.39	99.99
8	1.41	4.867E+03	1.109E+04	3.429E+05	30.91	100.01
9	0.97	4.492E+03	1.183E+04	3.132E+05	26.48	99.95
10	1.85	5.139E+03	1.086E+04	3.649E+05	33.60	100.02
11	2.29	5.362E+03	1.083E+04	3.821E+05	35.28	99.97
12	2.73	5.487E+03	1.064E+04	3.919E+05	36.84	100.00
13	3.17	5.582E+03	1.049E+04	3.990E+05	38.02	99.99
14	3.61	5.706E+03	1.054E+04	4.078E+05	38.57	99.95

Least-Squares Line for Ho vs q curve:

Slope = -2.9602E-01

Intercept = 7.7502E+05

Least-squares line for q = a*delta-T^{1/4}b

a = 2.6293E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH2T3

NOTE: 14 x-y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAN2T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.0949

Alpha (based on Nusselt (Tdel)) = 0.8014

Enhancement (q) = 1.063

Enhancement (Del-T) = 1.047

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	0.97	3.104E+03	1.352E+04	2.237E+05	16.55	100.04
2	1.41	3.591E+03	1.217E+04	2.597E+05	21.33	99.99
3	1.85	3.987E+03	1.191E+04	2.876E+05	24.14	99.99
4	2.29	4.290E+03	1.175E+04	3.092E+05	26.32	99.95
5	2.73	4.512E+03	1.149E+04	3.242E+05	28.21	99.94
6	3.17	4.716E+03	1.145E+04	3.387E+05	29.60	100.01
7	3.61	4.953E+03	1.122E+04	3.475E+05	30.97	99.99
8	3.17	4.734E+03	1.151E+04	3.376E+05	29.32	99.97
9	3.61	4.873E+03	1.131E+04	3.477E+05	30.73	99.94
10	2.73	4.531E+03	1.154E+04	3.218E+05	27.89	99.93
11	2.29	4.298E+03	1.168E+04	3.047E+05	26.09	99.94
12	1.85	3.969E+03	1.159E+04	2.813E+05	24.26	99.95
13	1.41	3.602E+03	1.201E+04	2.643E+05	21.18	99.95
14	0.97	3.164E+03	1.413E+04	2.226E+05	15.75	100.07

Least-Squares Line for Ho vs q curve:

Slope = -2.3609E-01

Intercept = 7.5845E+05

Least-squares line for q = a*delta-T^{1/4}b

a = 2.6571E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN2T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPCK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVH2T1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.0049
 Alpha (based on Nusselt (T_{del})) = 0.7965
 Enhancement (q) = 1.052
 Enhancement (Δ_{el}-T) = 1.038

Data #	U _w (m/s)	U _o (W/m ² -K)	Ho (W/m ² -K)	Q _p (W/m ²)	T _{cf} (C)	T _s (C)
1	3.64	5.753E+03	1.174E+04	1.466E+05	12.49	48.73
2	3.19	5.631E+03	1.181E+04	1.423E+05	12.04	48.69
3	2.75	5.462E+03	1.182E+04	1.363E+05	11.53	48.63
4	2.52	5.369E+03	1.186E+04	1.341E+05	11.31	48.80
5	2.30	5.263E+03	1.190E+04	1.315E+05	11.05	48.95
6	1.86	4.949E+03	1.172E+04	1.226E+05	10.46	48.70
7	1.42	4.621E+03	1.203E+04	1.132E+05	9.41	48.63
8	0.97	4.146E+03	1.277E+04	1.014E+05	7.94	48.80
9	0.97	4.229E+03	1.364E+04	1.035E+05	7.58	48.54
10	1.42	4.657E+03	1.230E+04	1.153E+05	9.37	48.65
11	1.86	5.011E+03	1.209E+04	1.247E+05	10.32	48.65
12	2.30	5.284E+03	1.203E+04	1.321E+05	10.98	48.66
13	2.53	5.348E+03	1.177E+04	1.341E+05	11.39	48.74

Least-Squares Line for Ho vs q curve:

Slope = -2.9344E-01

Intercept = 5.8163E+05

Least-squares line for q = a*Δ_{el}-T^{1.4}

a = 2.1707E+04

b = 7.5000E-01

NOTE: 13 data points were stored in file FONMVH2T1

NOTE: 13 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVH2T2

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.9482

Alpha (based on Nusselt (Tdel)) = 0.7873

Enhancement (q) = 1.035

Enhancement (Del-T) = 1.026

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.64	5.614E+03	1.134E+04	1.454E+05	12.92	48.64
2	3.19	5.552E+03	1.166E+04	1.425E+05	12.23	48.64
3	2.75	5.383E+03	1.168E+04	1.390E+05	11.82	48.75
4	2.53	5.288E+03	1.171E+04	1.348E+05	11.51	48.67
5	2.31	5.193E+03	1.181E+04	1.326E+05	11.22	48.77
6	1.86	4.952E+03	1.205E+04	1.263E+05	10.48	48.91
7	1.42	4.573E+03	1.213E+04	1.155E+05	9.52	48.68
8	0.97	4.107E+03	1.303E+04	1.024E+05	7.86	48.71
9	1.42	4.582E+03	1.219E+04	1.156E+05	9.49	48.70
10	0.97	4.121E+03	1.316E+04	1.025E+05	7.79	48.69
11	2.31	5.164E+03	1.167E+04	1.316E+05	11.28	48.66
12	3.64	5.630E+03	1.139E+04	1.443E+05	12.67	48.65
13	3.19	5.480E+03	1.134E+04	1.398E+05	12.33	48.58

Least-Squares Line for Ho vs q curve:

Slope = -3.2945E-01

Intercept = 5.8591E+05

Least-squares line for q = a*delta-T^{1.5}b

a = 2.1568E+04

b = 7.5000E-01

NOTE: 13 data points were stored in file FONMVH2T2

NOTE: 13 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVH2T3
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.2400
 Alpha (based on Nusselt (T_{del})) = 0.7662
 Enhancement (q) = .999
 Enhancement (Del-T) = .999

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.823E+03	1.143E+04	1.395E+05	12.20	48.63
2	3.18	5.684E+03	1.138E+04	1.353E+05	11.89	48.64
3	2.74	5.568E+03	1.155E+04	1.320E+05	11.43	48.63
4	2.30	5.354E+03	1.149E+04	1.267E+05	11.02	48.64
5	1.86	5.135E+03	1.170E+04	1.209E+05	10.33	48.65
6	1.41	4.825E+03	1.201E+04	1.132E+05	9.43	48.70
7	0.97	4.405E+03	1.300E+04	1.015E+05	7.81	48.71
8	1.41	4.927E+03	1.203E+04	1.138E+05	9.46	48.67
9	0.97	4.383E+03	1.292E+04	1.015E+05	7.92	48.72
10	1.86	5.126E+03	1.167E+04	1.223E+05	10.48	48.74
11	2.30	5.341E+03	1.145E+04	1.275E+05	11.14	48.62
12	2.74	5.553E+03	1.150E+04	1.334E+05	11.60	48.70
13	3.19	5.669E+03	1.133E+04	1.358E+05	11.99	48.61
14	3.63	5.802E+03	1.135E+04	1.400E+05	12.33	48.74

Least-Squares Line for Ho vs q curve:

Slope = -3.3576E-01
 Intercept = 5.8581E+05

Least-squares line for q = a*delta-T^b

a = 2.1177E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH2T3

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVN2T1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.95 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 0.9979
 Alpha (based on Nusselt (Tdel)) = 0.8181
 Enhancement (q) = .996
 Enhancement (Del-T) = .997

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	0.97	2.991E+03	1.622E+04	7.061E+04	4.35	48.71
2	1.41	3.543E+03	1.476E+04	9.456E+04	5.73	48.66
3	1.86	3.947E+03	1.394E+04	9.451E+04	6.79	48.66
4	2.30	4.306E+03	1.392E+04	1.032E+05	7.42	48.65
5	2.74	4.548E+03	1.342E+04	1.088E+05	8.10	48.67
6	2.74	4.582E+03	1.372E+04	1.092E+05	7.96	48.63
7	3.18	4.765E+03	1.322E+04	1.138E+05	8.61	48.69
8	3.63	5.009E+03	1.350E+04	1.194E+05	8.85	48.68
9	3.18	4.784E+03	1.334E+04	1.135E+05	8.51	48.66
10	3.63	4.978E+03	1.326E+04	1.182E+05	8.92	48.70
11	2.74	4.556E+03	1.345E+04	1.078E+05	8.02	48.72
12	2.30	4.311E+03	1.389E+04	1.016E+05	7.31	48.68
13	1.86	3.971E+03	1.413E+04	9.320E+04	6.59	48.70
14	1.41	3.548E+03	1.465E+04	8.254E+04	5.63	48.66
15	0.97	2.987E+03	1.585E+04	6.885E+04	4.34	48.71

Least-Squares Line for Ho vs q curve:

Slope = -2.6538E-01
 Intercept = 5.8038E+05

Least-squares line for q = a*delta-T^b

a = 2.2839E+04
 b = 7.5000E-01

NOTE: 15 data points were stored in file FONMVN2T1

NOTE: 15 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVN3T1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 0.9111
 Alpha (based on Nusselt (T_{del})) = 0.6359
 Enhancement (q) = .624
 Enhancement (Δ_l-T) = .702

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.64	4.261E+03	9.903E+03	1.078E+05	10.89	48.61
2	3.19	4.046E+03	9.629E+03	1.034E+05	10.73	48.86
3	2.75	3.864E+03	9.694E+03	9.833E+04	10.14	48.76
4	2.30	3.695E+03	1.016E+04	9.272E+04	9.13	48.43
5	1.86	3.435E+03	1.048E+04	8.615E+04	8.22	48.48
6	0.97	2.619E+03	1.170E+04	6.453E+04	5.52	48.49
7	1.42	3.070E+03	1.067E+04	7.722E+04	7.24	48.63
8	0.97	2.649E+03	1.238E+04	6.524E+04	5.27	48.32
9	1.42	3.072E+03	1.072E+04	7.736E+04	7.22	48.54
10	1.86	3.352E+03	9.765E+03	8.670E+04	8.88	49.08
11	2.31	3.716E+03	1.034E+04	9.406E+04	9.10	48.44
12	2.75	3.859E+03	9.681E+03	9.967E+04	10.30	48.92
13	3.19	4.091E+03	9.905E+03	1.040E+05	10.50	48.50
14	3.64	4.275E+03	9.995E+03	1.085E+05	10.66	48.49

Least-Squares Line for Ho vs q curve:
 Slope = -3.4927E-01
 Intercept = 5.8044E+05

Least-squares line for q = a*Δ_l-T^b
 a = 1.7709E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN3T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAH3T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.85 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.1377

Alpha (based on Nusselt (Tdel)) = 0.7239

Enhancement (q) = .872

Enhancement (Del-T) = .902

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Op (W/m^2)	Tof (C)	Ts (C)
1	3.62	5.173E+03	9.249E+03	3.780E+05	40.88	99.86
2	3.18	5.068E+03	9.251E+03	3.717E+05	40.18	100.01
3	2.74	4.950E+03	9.289E+03	3.634E+05	39.12	100.09
4	2.30	4.830E+03	9.456E+03	3.538E+05	37.41	99.96
5	1.85	4.616E+03	9.475E+03	3.377E+05	35.64	99.91
6	1.41	4.409E+03	9.947E+03	3.229E+05	32.46	100.11
7	0.97	4.014E+03	1.042E+04	2.923E+05	29.05	100.13
8	1.41	4.374E+03	9.784E+03	3.200E+05	32.70	99.81
9	0.97	4.028E+03	1.051E+04	2.924E+05	27.81	99.90
10	1.85	4.619E+03	9.508E+03	3.400E+05	35.76	99.92
11	2.30	4.790E+03	9.326E+03	3.539E+05	37.95	99.88
12	2.74	4.971E+03	9.385E+03	3.665E+05	39.05	99.75
13	3.18	5.054E+03	9.224E+03	3.749E+05	40.65	100.17
14	3.62	5.149E+03	9.135E+03	3.821E+05	41.58	100.15

Least-Squares Line for Ho vs q curve:

Slope = -3.3392E-01

Intercept = 7.7974E+05

Least-squares line for q = a*delta-T b

a = 2.3441E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH3T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAN3T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.0337

Alpha (based on Nusselt (Tdel)) = 0.6976

Enhancement (q) = .854

Enhancement (Del-T) = .838

Data #	Uw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Op (W/m^2)	Tof (C)	Ts (C)
1	3.63	4.380E+03	9.469E+03	3.271E+05	34.55	99.89
2	3.18	4.296E+03	9.764E+03	3.183E+05	32.60	99.60
3	2.74	4.068E+03	9.592E+03	3.044E+05	31.73	100.24
4	2.30	3.881E+03	9.813E+03	2.889E+05	29.44	99.97
5	1.86	3.576E+03	9.664E+03	2.665E+05	27.57	100.05
6	1.41	3.275E+03	1.023E+04	2.435E+05	23.79	99.97
7	0.97	2.867E+03	1.169E+04	2.120E+05	18.13	99.93
8	1.41	3.275E+03	1.025E+04	2.441E+05	23.81	99.99
9	0.97	2.863E+03	1.167E+04	2.123E+05	18.20	100.00
10	1.86	3.590E+03	9.795E+03	2.683E+05	27.40	100.01
11	2.30	3.860E+03	9.708E+03	2.988E+05	29.75	100.06
12	2.74	4.087E+03	9.713E+03	3.058E+05	31.49	100.00
13	3.18	4.250E+03	9.590E+03	3.178E+05	33.14	99.95
14	3.63	4.399E+03	9.560E+03	3.290E+05	34.42	99.97

Least-Squares Line for Ho vs q curve:

Slope = -2.8762E-01

Intercept = 7.6233E+05

Least-squares line for q = a*delta-T b

a = 2.2978E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN3T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVH3T2

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.8658

Alpha (based on Nusselt (Tdel)) = 0.6182

Enhancement (q) = .638

Enhancement (Del-T) = .714

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	0.97	3.760E+03	1.046E+04	8.859E+04	8.47	48.70
2	1.41	4.094E+03	9.489E+03	9.805E+04	10.33	48.72
3	1.86	4.370E+03	9.286E+03	1.049E+05	11.30	48.67
4	2.30	4.582E+03	9.216E+03	1.114E+05	12.09	48.83
5	2.74	4.733E+03	9.123E+03	1.144E+05	12.54	48.70
6	3.19	4.798E+03	9.870E+03	1.165E+05	13.14	48.78
7	3.63	4.986E+03	9.127E+03	1.207E+05	13.23	48.71
8	3.19	4.835E+03	8.993E+03	1.174E+05	13.06	48.88
9	3.63	4.991E+03	9.142E+03	1.206E+05	13.19	48.70
10	2.74	4.753E+03	9.191E+03	1.142E+05	12.43	48.74
11	2.30	4.573E+03	9.166E+03	1.093E+05	11.92	48.72
12	1.86	4.391E+03	9.389E+03	1.040E+05	11.10	48.65
13	1.41	4.130E+03	9.662E+03	9.732E+04	10.07	48.58
14	0.97	3.751E+03	1.036E+04	8.735E+04	8.43	48.72

Least-Squares Line for Ho vs q curve:

Slope = -4.1572E-01

Intercept = 5.8640E+05

Least-squares line for $q = a \cdot \Delta T^b$

a = 1.7233E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH3T2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAH4T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.3785

Alpha (based on Nusselt (Tdel)) = 0.8529

Enhancement (q) = 1.144

Enhancement (Del-T) = 1.106

Data #	Uw (m/s)	Uc (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.62	5.824E+03	1.114E+04	4.309E+05	38.63	99.98
2	3.18	5.742E+03	1.128E+04	4.235E+05	37.56	100.02
3	2.74	5.616E+03	1.136E+04	4.128E+05	36.34	99.96
4	2.30	5.449E+03	1.145E+04	3.989E+05	34.94	99.89
5	1.85	5.213E+03	1.152E+04	3.825E+05	33.19	100.07
6	1.41	4.921E+03	1.161E+04	3.593E+05	30.41	100.04
7	0.97	4.520E+03	1.273E+04	3.276E+05	25.72	99.95
8	1.41	4.901E+03	1.171E+04	3.586E+05	30.62	100.03
9	0.97	4.519E+03	1.272E+04	3.274E+05	25.74	99.97
10	1.85	5.226E+03	1.160E+04	3.838E+05	33.10	99.96
11	2.30	5.444E+03	1.144E+04	4.006E+05	35.01	100.00
12	2.74	5.614E+03	1.136E+04	4.135E+05	36.40	99.95
13	3.18	5.713E+03	1.116E+04	4.209E+05	37.71	99.98
14	3.62	5.910E+03	1.108E+04	4.290E+05	38.64	99.99

Least-Squares Line for Ho vs q curve:

Slope = -2.6757E-01

Intercept = 7.7418E+05

Least-squares line for q = a*delta-T^b

a = 2.7891E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH4T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAN4T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.3768

Alpha (based on Nusselt (Tdel)) = 0.7912

Enhancement (q) = 1.045

Enhancement (Del-T) = 1.034

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.090E+03	1.092E+04	3.804E+05	34.85	99.98
2	3.18	4.936E+03	1.089E+04	3.658E+05	33.58	99.94
3	2.74	4.757E+03	1.092E+04	3.519E+05	32.20	99.99
4	2.30	4.522E+03	1.089E+04	3.336E+05	30.62	99.97
5	1.85	4.214E+03	1.078E+04	3.103E+05	28.79	99.95
6	1.41	3.872E+03	1.109E+04	2.848E+05	25.69	99.95
7	0.97	3.497E+03	1.310E+04	2.558E+05	19.52	100.00
8	1.41	3.364E+03	1.104E+04	2.848E+05	25.30	99.97
9	0.97	3.519E+03	1.343E+04	2.573E+05	19.15	99.91
10	1.86	4.211E+03	1.079E+04	3.114E+05	28.86	99.94
11	2.30	4.527E+03	1.094E+04	3.348E+05	30.61	99.95
12	2.74	4.751E+03	1.090E+04	3.513E+05	32.24	99.92
13	3.18	4.945E+03	1.093E+04	3.662E+05	33.60	99.97
14	3.62	5.101E+03	1.093E+04	3.776E+05	34.66	99.97

Least-Squares Line for Ho vs q curve:

Slope = -2.4793E-01

Intercept = 7.6032E-05

Least-squares line for q = a*delta-T^b

a = 2.6008E-04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN4T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVH4T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.0810

Alpha (based on Nusselt (Tdel)) = 0.8211

Enhancement (q) = 1.095

Enhancement (Del-T) = 1.071

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.967E+03	1.241E+04	1.468E+05	11.83	48.70
2	3.19	5.798E+03	1.229E+04	1.417E+05	11.52	48.70
3	2.74	5.668E+03	1.251E+04	1.380E+05	11.03	48.74
4	2.30	5.424E+03	1.239E+04	1.313E+05	10.59	48.70
5	1.86	5.192E+03	1.272E+04	1.252E+05	9.85	48.73
6	1.41	4.872E+03	1.326E+04	1.168E+05	8.81	48.74
7	0.97	4.393E+03	1.440E+04	1.038E+05	7.21	48.67
8	1.41	4.884E+03	1.337E+04	1.175E+05	8.79	48.67
9	0.97	4.402E+03	1.451E+04	1.044E+05	7.20	48.70
10	1.86	5.207E+03	1.282E+04	1.263E+05	9.95	48.72
11	2.30	5.449E+03	1.254E+04	1.327E+05	10.58	48.69
12	2.74	5.653E+03	1.244E+04	1.377E+05	11.07	48.69
13	3.19	5.793E+03	1.226E+04	1.407E+05	11.48	48.76
14	3.63	5.943E+03	1.229E+04	1.441E+05	11.73	48.70

Least-Squares Line for Ho vs q curve:

Slope = -3.1730E-01

Intercept = 5.8664E+05

Least-squares line for q = a*delta-T^b

a = 2.2845E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH4T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVN4T1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.1394
 Alpha (based on Nusselt (Tdel)) = 0.8245
 Enhancement (q) = 1.007
 Enhancement (Del-T) = 1.005

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.64	5.167E+03	1.309E+04	1.307E+05	9.99	48.71
2	3.19	4.973E+03	1.310E+04	1.248E+05	9.53	48.66
3	2.75	4.780E+03	1.339E+04	1.196E+05	8.93	48.68
4	2.30	4.490E+03	1.333E+04	1.121E+05	8.41	48.67
5	1.86	4.130E+03	1.322E+04	1.029E+05	7.79	48.70
6	1.42	3.722E+03	1.369E+04	9.235E+04	6.75	48.66
7	0.97	3.186E+03	1.500E+04	7.819E+04	5.21	48.70
8	1.42	3.727E+03	1.377E+04	9.296E+04	6.75	48.74
9	0.97	3.205E+03	1.544E+04	7.870E+04	5.10	48.70
10	1.86	4.125E+03	1.319E+04	1.032E+05	7.83	48.67
11	2.30	4.483E+03	1.330E+04	1.127E+05	8.47	48.67
12	2.75	4.737E+03	1.308E+04	1.197E+05	9.15	48.72
13	3.19	4.955E+03	1.299E+04	1.257E+05	9.68	48.74
14	3.64	5.165E+03	1.309E+04	1.311E+05	10.02	48.69
15	2.30	4.473E+03	1.321E+04	1.127E+05	8.53	48.72
16	0.97	3.210E+03	1.559E+04	7.913E+04	5.07	48.70
17	3.64	5.150E+03	1.301E+04	1.315E+05	10.11	48.71

Least-Squares Line for Ho vs q curve:
 Slope = -2.6143E-01
 Intercept = 5.7985E+05

Least-squares line for q = a*delta-T^b
 a = 2.2773E+04
 b = 7.5000E-01

NOTE: 17 data points were stored in file FONMVN4T1

NOTE: 17 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAHST1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.2507
 Alpha (based on Nusselt (Tdel)) = 0.8691
 Enhancement (q) = 1.173
 Enhancement (Del-T) = 1.127

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.60	5.914E+03	1.155E+04	4.113E+05	35.61	99.96
2	3.16	5.820E+03	1.165E+04	4.011E+05	34.43	100.02
3	2.72	5.727E+03	1.189E+04	3.917E+05	32.93	100.03
4	2.28	5.544E+03	1.196E+04	3.769E+05	31.52	99.92
5	1.84	5.333E+03	1.220E+04	3.613E+05	29.62	100.03
6	1.40	5.012E+03	1.244E+04	3.367E+05	27.07	99.95
7	0.96	4.578E+03	1.333E+04	3.054E+05	22.91	99.99
8	1.40	5.013E+03	1.246E+04	3.375E+05	27.09	99.93
9	0.96	4.582E+03	1.335E+04	3.055E+05	22.99	100.02
10	1.84	5.323E+03	1.216E+04	3.607E+05	29.68	99.92
11	2.28	5.574E+03	1.209E+04	3.785E+05	31.30	99.97
12	2.72	5.745E+03	1.196E+04	3.907E+05	32.69	99.99
13	3.15	5.848E+03	1.173E+04	3.975E+05	33.88	99.96
14	3.59	5.979E+03	1.174E+04	4.064E+05	34.50	99.95
15	3.15	5.826E+03	1.154E+04	3.949E+05	33.93	99.99
16	3.59	5.992E+03	1.180E+04	4.066E+05	34.47	99.97

Least-Squares Line for Ho vs q curve:
 Slope = -2.4930E-01
 Intercept = 7.6900E+05

Least-squares line for q = a*delta-T^b
 a = 2.8492E+04
 b = 7.5000E-01

NOTE: 16 data points were stored in file FONMAHST1

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMANST1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 1.0988

Alpha (based on Nusselt (T_{del})) = 0.9367

Enhancement (q) = 1.126

Enhancement (Δ_l-T) = 1.093

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.16	4.852E+03	1.203E+04	3.362E+05	27.95	99.95
2	2.72	4.685E+03	1.233E+04	3.227E+05	26.16	99.92
3	2.28	4.429E+03	1.238E+04	3.042E+05	24.57	100.01
4	1.84	4.108E+03	1.244E+04	2.809E+05	22.58	99.95
5	1.40	3.720E+03	1.286E+04	2.539E+05	19.74	100.04
6	0.96	3.248E+03	1.494E+04	2.203E+05	14.74	99.91
7	1.40	3.709E+03	1.279E+04	2.538E+05	19.95	99.92
8	0.96	3.235E+03	1.471E+04	2.200E+05	14.95	99.96
9	1.84	4.106E+03	1.249E+04	2.825E+05	22.63	99.95
10	2.28	4.423E+03	1.237E+04	3.052E+05	24.67	100.02
11	2.72	4.682E+03	1.232E+04	3.235E+05	26.26	100.03
12	3.61	5.010E+03	1.198E+04	3.534E+05	29.50	100.00
13	3.17	4.845E+03	1.219E+04	3.473E+05	28.49	99.93
14	3.61	5.004E+03	1.204E+04	3.592E+05	29.84	100.02

Least-Squares Line for Ho vs q curve:

Slope = -2.1506E-01

Intercept = 7.5527E+05

Least-squares line for q = a*Δ_l-T^b

a = 2.7811E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANST1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVHST1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.96 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.0139

Alpha (based on Nusselt (Tdel)) = 0.8415

Enhancement (q) = 1.132

Enhancement (Del-T) = 1.097

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	6.026E+03	1.281E+04	1.423E+05	11.11	48.66
2	3.18	5.928E+03	1.304E+04	1.376E+05	10.55	48.70
3	2.74	5.738E+03	1.301E+04	1.308E+05	10.05	48.61
4	2.30	5.558E+03	1.329E+04	1.254E+05	9.43	48.61
5	1.85	5.293E+03	1.354E+04	1.196E+05	8.76	48.71
6	1.41	4.928E+03	1.394E+04	1.093E+05	7.84	48.73
7	0.97	4.410E+03	1.497E+04	9.625E+04	6.43	48.70
8	1.41	4.910E+03	1.381E+04	1.091E+05	7.90	48.68
9	0.97	4.407E+03	1.493E+04	9.616E+04	6.44	48.71
10	1.85	5.301E+03	1.360E+04	1.188E+05	8.74	48.55
11	2.30	5.540E+03	1.318E+04	1.248E+05	9.47	48.68
12	2.74	5.772E+03	1.316E+04	1.302E+05	9.89	48.66
13	3.18	5.911E+03	1.292E+04	1.336E+05	10.34	48.72
14	3.62	6.113E+03	1.314E+04	1.371E+05	10.43	48.65
15	2.29	5.556E+03	1.325E+04	1.235E+05	9.32	48.73
16	3.62	6.097E+03	1.306E+04	1.364E+05	10.44	48.69

Least-Squares Line for Ho vs q curve:

Slope = -2.8741E-01

Intercept = 5.9357E+05

Least-squares line for q = a*delta-T^b

a = 2.3376E+04

b = 7.5000E-01

NOTE: 16 data points were stored in file FONMVHST1

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVNST1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 0.9775

Alpha (based on Nusselt (T_{del})) = 0.8425

Enhancement (q) = 1.036

Enhancement (Δ_L-T) = 1.027

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	4.995E+03	1.364E+04	1.180E+05	8.65	48.71
2	3.18	4.834E+03	1.401E+04	1.122E+05	8.01	48.62
3	2.74	4.638E+03	1.449E+04	1.068E+05	7.37	48.58
4	2.30	4.365E+03	1.480E+04	9.953E+04	6.73	48.55
5	1.85	3.996E+03	1.484E+04	9.080E+04	6.12	48.72
6	1.41	3.561E+03	1.539E+04	7.982E+04	5.19	48.62
7	0.97	2.998E+03	1.665E+04	6.614E+04	3.97	48.63
8	1.41	3.545E+03	1.511E+04	7.963E+04	5.27	48.62
9	0.97	2.989E+03	1.670E+04	6.637E+04	3.98	48.57
10	1.85	4.001E+03	1.493E+04	9.108E+04	6.10	48.57
11	2.30	4.334E+03	1.446E+04	9.877E+04	6.83	48.63
12	2.74	4.628E+03	1.436E+04	1.059E+05	7.37	48.70
13	3.18	4.830E+03	1.392E+04	1.104E+05	7.93	48.65
14	3.62	5.056E+03	1.401E+04	1.156E+05	8.25	48.72
15	2.29	4.348E+03	1.455E+04	9.797E+04	6.73	48.55
16	0.97	3.024E+03	1.763E+04	6.615E+04	3.75	48.59

Least-Squares Line for Ho vs q curve:

Slope = -2.4722E-01

Intercept = 5.7933E+05

Least-squares line for q = a*Δ_L-T^b

a = 2.3546E+04

b = 7.5000E-01

NOTE: 16 data points were stored in file FONMVNST1

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAH6T2

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.3893

Alpha (based on Nusselt (Tdel)) = 0.9933

Enhancement (q) = 1.402

Enhancement (Del-T) = 1.299

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	1.85	5.666E+03	1.385E+04	4.083E+05	29.48	99.95
2	1.41	5.331E+03	1.432E+04	3.841E+05	26.83	99.98
3	0.97	4.821E+03	1.517E+04	3.453E+05	22.76	100.08
4	1.41	5.328E+03	1.432E+04	3.844E+05	26.84	99.99
5	0.97	4.842E+03	1.540E+04	3.475E+05	22.56	100.09
6	1.85	5.679E+03	1.397E+04	4.132E+05	29.58	100.05
7	2.29	5.932E+03	1.374E+04	4.326E+05	31.47	99.99
8	2.74	6.114E+03	1.354E+04	4.465E+05	32.98	99.97
9	3.18	6.271E+03	1.345E+04	4.584E+05	34.08	99.95
10	3.62	6.379E+03	1.330E+04	4.668E+05	35.10	100.01
11	3.18	6.278E+03	1.347E+04	4.585E+05	34.03	100.06
12	3.62	6.392E+03	1.335E+04	4.674E+05	35.01	100.04
13	2.74	6.130E+03	1.360E+04	4.460E+05	32.80	100.00
14	2.29	5.932E+03	1.372E+04	4.308E+05	31.40	100.02

Least-Squares Line for Ho vs q curve:

Slope = -2.1689E-01

Intercept = 7.6861E+05

Least-squares line for q = a*delta-T^b

a = 3.2616E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH6T2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAH6T3

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.3616

Alpha (based on Nusselt (Tdel)) = 1.0051

Enhancement (q) = 1.425

Enhancement (Del-T) = 1.304

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.62	6.405E+03	1.350E+04	4.721E+05	34.97	100.05
2	3.18	6.279E+03	1.356E+04	4.601E+05	33.89	99.99
3	2.74	6.154E+03	1.383E+04	4.500E+05	32.55	100.01
4	2.29	5.949E+03	1.394E+04	4.334E+05	31.09	99.93
5	1.85	5.704E+03	1.425E+04	4.142E+05	29.06	99.89
6	1.41	5.321E+03	1.446E+04	3.857E+05	26.68	100.01
7	0.97	4.925E+03	1.557E+04	3.481E+05	22.36	100.02
8	1.41	5.333E+03	1.456E+04	3.974E+05	29.61	100.05
9	2.30	5.951E+03	1.397E+04	4.349E+05	31.14	99.91
10	3.18	6.274E+03	1.355E+04	4.611E+05	34.02	100.01

Least-Squares Line for Ho vs q curve:

Slope = -2.1564E-01

Intercept = 7.6915E+05

Least-squares line for q = a*delta-T*^b

a = 3.3011E+04

b = 7.5000E-01

NOTE: 10 data points were stored in file FONMAH6T3

NOTE: 10 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMANST1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.86 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.1204
 Alpha (based on Nusselt (Tdel)) = 1.0190
 Enhancement (q) = 1.465
 Enhancement (Del-T) = 1.331

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.62	5.436E+03	1.471E+04	3.946E+05	25.83	99.98
2	3.17	5.295E+03	1.527E+04	3.831E+05	25.10	99.98
3	2.73	5.044E+03	1.531E+04	3.643E+05	23.79	99.91
4	2.29	4.772E+03	1.571E+04	3.446E+05	21.93	99.93
5	1.85	4.410E+03	1.601E+04	3.186E+05	19.89	100.03
6	1.41	3.939E+03	1.638E+04	2.839E+05	17.33	99.93
7	0.97	3.365E+03	1.860E+04	2.419E+05	13.01	100.02
8	1.41	3.915E+03	1.605E+04	2.837E+05	17.59	100.07
9	0.97	3.370E+03	1.881E+04	2.421E+05	12.87	99.97
10	1.85	4.404E+03	1.605E+04	3.197E+05	19.92	99.93
11	2.29	4.762E+03	1.569E+04	3.458E+05	22.04	99.91
12	2.73	5.056E+03	1.548E+04	3.669E+05	23.71	99.97
13	3.17	5.290E+03	1.523E+04	3.826E+05	25.12	99.89
14	3.62	5.472E+03	1.495E+04	3.960E+05	25.50	99.98

Least-Squares Line for Ho vs q curve:

Slope = -1.7416E-01

Intercept = 7.5469E+05

Least-squares line for q = a+delta-T^b

a = 3.4038E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANST1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVH6T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.1602

Alpha (based on Nusselt (T_{del})) = 0.9498

Enhancement (q) = 1.330

Enhancement (Δ_l-T) = 1.238

Data #	U _w (m/s)	U _o (W/m ² -K)	Ho (W/m ² -K)	Q _p (W/m ²)	T _{cf} (C)	T _s (C)
1	3.63	6.503E+03	1.468E+04	1.502E+05	10.92	48.76
2	3.19	6.324E+03	1.459E+04	1.530E+05	10.48	48.55
3	2.74	6.140E+03	1.468E+04	1.489E+05	10.14	48.73
4	2.30	5.961E+03	1.514E+04	1.430E+05	9.45	48.59
5	1.86	5.626E+03	1.512E+04	1.352E+05	8.94	48.75
6	0.97	4.703E+03	1.707E+04	1.099E+05	6.44	48.65
7	1.41	5.222E+03	1.549E+04	1.246E+05	8.04	48.67
8	2.30	5.930E+03	1.495E+04	1.430E+05	9.57	48.64
9	3.19	6.329E+03	1.462E+04	1.540E+05	10.53	48.67
10	1.41	5.229E+03	1.554E+04	1.241E+05	7.99	48.59

Least-Squares Line for Ho vs q curve:

Slope = -2.4792E-01

Intercept = 5.8256E+05

Least-squares line for q = a*Δ_l-T^b

a = 2.6385E+04

b = 7.5000E-01

NOTE: 10 data points were stored in file FONMVH6T1

NOTE: 10 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVH6T2

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.2144

Alpha (based on Nusselt (T_{del})) = 0.9460

Enhancement (q) = 1.323

Enhancement (Δ_l-T) = 1.233

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	6.476E+03	1.438E+04	1.610E+05	11.20	48.70
2	3.19	6.318E+03	1.439E+04	1.570E+05	10.91	48.80
3	2.75	6.157E+03	1.459E+04	1.516E+05	10.39	48.64
4	2.30	5.945E+03	1.481E+04	1.454E+05	9.82	48.58
5	1.96	5.645E+03	1.498E+04	1.380E+05	9.21	48.65
6	1.42	5.228E+03	1.518E+04	1.278E+05	8.42	48.74
7	0.97	4.712E+03	1.663E+04	1.125E+05	6.77	48.65
8	1.42	5.250E+03	1.538E+04	1.287E+05	8.37	48.76
9	0.97	4.715E+03	1.667E+04	1.128E+05	6.77	48.66
10	1.86	5.635E+03	1.492E+04	1.382E+05	9.26	48.62
11	2.30	5.932E+03	1.474E+04	1.457E+05	9.88	48.56
12	2.75	6.159E+03	1.461E+04	1.523E+05	10.42	48.66
13	3.19	6.331E+03	1.447E+04	1.572E+05	10.86	48.71
14	3.63	6.490E+03	1.445E+04	1.610E+05	11.14	48.67

Least-Squares Line for Ho vs q curve:

Slope = -2.4920E-01

Intercept = 5.8254E+05

Least-squares line for q = a*Δ_l-T^b

a = 2.6267E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH6T2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVN6T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0427

Alpha (based on Nusselt (Tdel)) = 1.0131

Enhancement (q) = 1.325

Enhancement (Del-T) = 1.235

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.471E+03	1.674E+04	1.360E+05	8.12	48.58
2	3.19	5.271E+03	1.713E+04	1.308E+05	7.64	48.63
3	2.75	5.035E+03	1.768E+04	1.244E+05	7.04	48.60
4	2.30	4.697E+03	1.769E+04	1.156E+05	6.53	48.58
5	1.86	4.296E+03	1.786E+04	1.059E+05	5.93	48.72
6	1.42	3.804E+03	1.938E+04	9.338E+04	5.08	48.70
7	0.97	3.210E+03	2.134E+04	7.770E+04	3.64	48.60
8	1.42	3.800E+03	1.834E+04	9.400E+04	5.13	48.75
9	0.97	3.201E+03	2.101E+04	7.757E+04	3.69	48.56
10	1.86	4.293E+03	1.790E+04	1.070E+05	5.98	48.77
11	2.30	4.693E+03	1.771E+04	1.169E+05	6.60	48.64
12	2.75	5.044E+03	1.794E+04	1.255E+05	7.04	48.57
13	3.19	5.276E+03	1.721E+04	1.313E+05	7.63	48.53
14	3.63	5.473E+03	1.677E+04	1.370E+05	8.17	48.69

Least-Squares Line for Ho vs q curve:

Slope = -2.0780E-01

Intercept = 5.7958E+05

Least-squares line for $q = a \cdot \Delta T^b$

a = 2.8413E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN6T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAH7T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.2365

Alpha (based on Nusselt (T_{del})) = 0.9248

Enhancement (q) = 1.275

Enhancement (Δ_l-T) = 1.200

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.61	6.067E+03	1.228E+04	4.375E+05	35.62	99.94
2	3.17	5.979E+03	1.243E+04	4.232E+05	34.06	99.94
3	2.73	5.823E+03	1.245E+04	4.095E+05	32.90	100.11
4	2.28	5.662E+03	1.267E+04	3.948E+05	31.17	99.96
5	1.84	5.397E+03	1.271E+04	3.745E+05	29.47	100.06
6	1.40	5.073E+03	1.306E+04	3.503E+05	26.82	99.95
7	0.97	4.609E+03	1.428E+04	3.254E+05	22.79	99.97
8	1.41	5.051E+03	1.321E+04	3.635E+05	27.52	99.93
9	0.97	4.604E+03	1.446E+04	3.310E+05	22.90	99.95
10	1.41	5.045E+03	1.323E+04	3.666E+05	27.70	100.00
11	1.85	5.360E+03	1.290E+04	3.936E+05	30.52	100.09
12	2.30	5.618E+03	1.267E+04	4.123E+05	32.55	100.06
13	2.74	5.829E+03	1.265E+04	4.282E+05	33.85	100.00
14	3.18	5.974E+03	1.253E+04	4.393E+05	35.06	99.97
15	3.62	6.062E+03	1.232E+04	4.465E+05	36.24	100.06
16	3.18	5.973E+03	1.252E+04	4.383E+05	35.01	99.96
17	3.62	6.070E+03	1.235E+04	4.467E+05	36.18	100.09
18	2.74	5.845E+03	1.271E+04	4.282E+05	33.68	99.97
19	2.30	5.630E+03	1.272E+04	4.117E+05	32.37	99.98
20	1.85	5.380E+03	1.288E+04	3.922E+05	30.44	100.02

Least-Squares Line for Ho vs q curve:

Slope = -2.2991E-01

Intercept = 7.6695E+05

Least-squares line for q = a*Δ_l-T^{1.5}

a = 3.0311E+04

b = 7.5000E-01

NOTE: 20 data points were stored in file FONMAH7T1

NOTE: 20 X-Y pairs were stored in data file

NOTE: Program name : DRPGT
 Data taken by : O'KEEFE
 This analysis done on file : FONMAN7T1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.36 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 1.1913
 Alpha (based on Nusselt (T_{del})) = 0.3660
 Enhancement (q) = 1.179
 Enhancement (Δ_l-T) = 1.131

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.149E+03	1.232E+04	3.930E+05	31.09	99.96
2	3.18	4.963E+03	1.228E+04	3.679E+05	29.95	99.99
3	2.74	4.764E+03	1.240E+04	3.532E+05	28.48	100.06
4	2.30	4.500E+03	1.242E+04	3.338E+05	26.88	100.08
5	1.86	4.189E+03	1.259E+04	3.100E+05	24.63	99.98
6	1.41	3.795E+03	1.299E+04	2.809E+05	21.61	100.08
7	0.97	3.319E+03	1.507E+04	2.442E+05	16.21	99.91
8	1.41	3.786E+03	1.292E+04	2.808E+05	21.73	100.06
9	0.97	3.308E+03	1.488E+04	2.439E+05	16.39	99.97
10	1.86	4.185E+03	1.261E+04	3.113E+05	24.69	99.97
11	2.30	4.491E+03	1.240E+04	3.345E+05	26.98	100.01
12	2.74	4.764E+03	1.243E+04	3.540E+05	29.47	99.90
13	3.18	4.968E+03	1.234E+04	3.698E+05	29.97	100.03
14	3.63	5.151E+03	1.232E+04	3.931E+05	31.09	100.24

Least-Squares Line for Ho vs q curve:

Slope = -2.1515E-01
 Intercept = 7.5742E+05

Least-squares line for q = a*Δ_l-T^b

a = 2.8701E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN7T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DROST

Data taken by : O'KEEFE

This analysis done on file : FONMVH7T2

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.9553

Alpha (based on Nusselt (Tdel)) = 0.8552

Enhancement (q) = 1.156

Enhancement (Del-T) = 1.115

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	2.30	5.539E+03	1.355E+04	1.303E+05	9.61	48.63
2	1.86	5.230E+03	1.359E+04	1.219E+05	8.97	48.53
3	1.41	4.865E+03	1.405E+04	1.131E+05	8.05	48.69
4	0.97	4.349E+03	1.526E+04	1.006E+05	6.59	48.72
5	1.41	4.842E+03	1.387E+04	1.135E+05	8.18	48.72
6	1.41	4.871E+03	1.412E+04	1.136E+05	8.05	48.63
7	1.86	5.237E+03	1.365E+04	1.239E+05	9.07	48.70
8	2.30	5.516E+03	1.343E+04	1.305E+05	9.71	48.56
9	2.74	5.738E+03	1.332E+04	1.364E+05	10.25	48.64
10	3.18	5.896E+03	1.309E+04	1.408E+05	10.76	48.79
11	3.63	6.067E+03	1.320E+04	1.441E+05	10.92	48.53
12	3.18	5.872E+03	1.301E+04	1.405E+05	10.79	48.80
13	2.74	5.721E+03	1.322E+04	1.355E+05	10.25	48.69
14	2.30	5.544E+03	1.359E+04	1.307E+05	9.62	48.62

Least-Squares Line for Ho vs q curve:

Slope = -2.9347E-01

Intercept = 5.8361E+05

Least-squares line for q = a*delta-T^b

a = 2.3773E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH7T2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPCQT

Data taken by : O'KEEFE

This analysis done on file : FONMUN7T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 0.9775

Alpha (based on Nusselt (Tdel)) = 0.8700

Enhancement (q) = 1.081

Enhancement (Del-T) = 1.060

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.069E+03	1.436E+04	1.240E+05	8.64	48.53
2	3.19	4.829E+03	1.413E+04	1.180E+05	8.35	48.74
3	2.74	4.658E+03	1.490E+04	1.125E+05	7.55	48.61
4	2.30	4.341E+03	1.480E+04	1.052E+05	7.11	48.78
5	1.86	3.967E+03	1.477E+04	9.574E+04	6.48	48.81
6	1.41	3.557E+03	1.583E+04	8.537E+04	5.39	48.75
7	0.97	2.997E+03	1.783E+04	7.072E+04	3.97	48.56
8	1.41	3.562E+03	1.596E+04	8.559E+04	5.36	48.68
9	0.97	2.977E+03	1.719E+04	7.082E+04	4.12	48.67
10	1.86	3.983E+03	1.505E+04	9.639E+04	6.41	48.68
11	2.30	4.339E+03	1.490E+04	1.051E+05	7.10	48.67
12	2.74	4.633E+03	1.465E+04	1.127E+05	7.70	48.76
13	3.19	4.828E+03	1.410E+04	1.180E+05	8.37	48.85
14	3.63	5.090E+03	1.447E+04	1.236E+05	8.54	48.72

Least-Squares Line for Ho vs q curve:

Slope = -2.4125E-01

Intercept = 5.7963E+05

Least-squares line for q = a*delta-T^b

a = 2.4307E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMUN7T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRBOK
 897
 Data taken by : O'KEEFE
 This analysis done on file : FONMAHLT2
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.47 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : LPD KORODENSE TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C_i (based on Petukhov-Popov) = 2.9032
 Alpha (based on Nusselt (T_{del})) = 0.9029
 Enhancement (q) = 1.235
 Enhancement (Δ_i-T) = 1.171

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	1.03	4.746E+03	1.321E+04	3.432E+05	25.98	100.00
2	1.49	5.182E+03	1.291E+04	3.747E+05	29.04	100.01
3	1.96	5.431E+03	1.255E+04	3.909E+05	31.14	100.05
4	2.43	5.611E+03	1.238E+04	4.029E+05	32.56	99.95
5	2.89	5.757E+03	1.231E+04	4.129E+05	33.54	99.99
6	3.36	5.842E+03	1.213E+04	4.175E+05	34.41	99.95
7	3.82	5.919E+03	1.204E+04	4.222E+05	35.07	99.99
8	3.35	5.833E+03	1.208E+04	4.143E+05	34.30	99.99
9	3.82	5.926E+03	1.206E+04	4.208E+05	34.89	100.02
10	2.89	5.755E+03	1.226E+04	4.069E+05	33.18	99.97
11	2.42	5.629E+03	1.242E+04	3.985E+05	32.09	99.95
12	1.96	5.433E+03	1.254E+04	3.881E+05	30.96	99.93
13	1.49	5.176E+03	1.282E+04	3.708E+05	29.93	100.02
14	1.03	4.765E+03	1.326E+04	3.401E+05	25.64	99.91

Least-Squares Line for Ho vs q curve:

Slope = -2.4802E-01

Intercept = 7.7226E+05

Least-squares line for q = a+Δ_i-T^b

a = 2.9569E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHLT2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

651
Data taken by : O'KEEFE

This analysis done on file : FONMAHLT3

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.47 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : LPD KORODENSE TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.8921

Alpha (based on Nusselt (Tdel)) = 0.9159

Enhancement (q) = 1.259

Enhancement (Del-T) = 1.188

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.83	5.902E+03	1.203E+04	4.313E+05	35.84	100.05
2	3.36	5.842E+03	1.219E+04	4.256E+05	34.90	99.93
3	2.90	5.778E+03	1.247E+04	4.206E+05	33.74	100.04
4	2.43	5.625E+03	1.250E+04	4.085E+05	32.67	100.01
5	1.96	5.466E+03	1.230E+04	3.958E+05	30.93	99.97
6	1.49	5.195E+03	1.302E+04	3.754E+05	28.83	99.94
7	1.03	4.782E+03	1.348E+04	3.429E+05	25.44	99.94
8	1.96	5.431E+03	1.262E+04	3.949E+05	31.29	100.03
9	2.43	5.647E+03	1.262E+04	4.114E+05	32.59	99.97
10	2.90	5.783E+03	1.250E+04	4.219E+05	33.76	99.99
11	3.83	5.929E+03	1.215E+04	4.335E+05	35.67	99.95

Least-Squares Line for Ho vs q curve:

Slope = -2.4475E-01

Intercept = 7.7234E+05

Least-squares line for q = a*delta-T^b

a = 2.9951E+04

b = 7.5000E-01

NOTE: 11 data points were stored in file FONMAHLT3

NOTE: 11 X-Y pairs were stored in data file

NOTE: Program name : DROCK

091
Data taken by : O'KEEFE

This analysis done on file : FONMANLT2

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.47 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : LPD KORODENSE TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.0556

Alpha (based on Nusselt (Toel)) = 0.9191

Enhancement (q) = 1.276

Enhancement (Del-T) = 1.201

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	2.43	5.306E+03	1.317E+04	3.858E+05	29.30	99.96
2	1.96	5.055E+03	1.324E+04	3.664E+05	27.68	100.07
3	1.49	4.759E+03	1.376E+04	3.428E+05	24.91	99.88
4	1.03	4.246E+03	1.411E+04	3.054E+05	21.64	100.03
5	1.49	4.724E+03	1.350E+04	3.419E+05	25.32	99.98
6	1.03	4.253E+03	1.420E+04	3.057E+05	21.53	99.90
7	1.96	5.053E+03	1.325E+04	3.677E+05	27.74	100.05
8	2.43	5.297E+03	1.310E+04	3.847E+05	29.35	99.95
9	2.90	5.451E+03	1.293E+04	3.960E+05	30.85	99.94
10	3.36	5.578E+03	1.266E+04	4.051E+05	31.99	99.98
11	3.83	5.632E+03	1.231E+04	4.086E+05	33.20	99.87
12	3.36	5.569E+03	1.261E+04	4.042E+05	32.05	100.07
13	3.83	5.636E+03	1.232E+04	4.088E+05	33.19	100.02
14	2.89	5.460E+03	1.286E+04	3.951E+05	30.73	100.11

Least-Squares Line for Ho vs q curve:

Slope = -2.2869E-01

Intercept = 7.6648E+05

Least-squares line for q = a*delta-T^b

a = 3.0263E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANLT2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRACUT

Data taken by : O'KEEFE

This analysis done on file : FONMANLT3

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.47 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : LPD KORODENSE TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.9930

Alpha (based on Nusselt (Tdel)) = 0.9411

Enhancement (q) = 1.317

Enhancement (Del-T) = 1.230

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	2.43	5.283E+03	1.333E+04	3.852E+05	29.91	99.85
2	1.96	5.049E+03	1.355E+04	3.662E+05	27.02	99.94
3	1.49	4.761E+03	1.425E+04	3.439E+05	24.13	100.03
4	1.03	4.246E+03	1.475E+04	3.046E+05	20.64	99.96
5	1.49	4.751E+03	1.417E+04	3.432E+05	24.22	100.00
6	1.03	4.253E+03	1.482E+04	3.048E+05	20.56	99.97
7	1.96	5.078E+03	1.375E+04	3.674E+05	26.72	99.93
8	2.43	5.316E+03	1.349E+04	3.855E+05	28.57	100.03
9	2.89	5.464E+03	1.313E+04	3.963E+05	30.18	99.94
10	3.36	5.593E+03	1.294E+04	4.063E+05	31.40	100.09
11	3.83	5.664E+03	1.263E+04	4.113E+05	32.57	100.04

Least-Squares Line for Ho vs q curve:

Slope = -2.2725E-01

Intercept = 7.6783E+05

Least-squares line for q = a*delta-T^b

a = 3.1076E+04

b = 7.5000E-01

NOTE: 11 data points were stored in file FONMANLT3

NOTE: 11 X-Y pairs were stored in data file

NOTE: Program name : DREGT
 Data taken by : O'KEEFE
 This analysis done on file : FONMVHLT1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.47 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : LPD KORODENSE TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.7173
 Alpha (based on Nusselt (T_{del})) = 0.9449
 Enhancement (q) = 1.321
 Enhancement (Δ_l-T) = 1.232

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	1.03	4.900E+03	1.624E+04	1.195E+05	7.36	48.68
2	1.50	5.386E+03	1.546E+04	1.316E+05	8.51	48.69
3	1.97	5.700E+03	1.506E+04	1.397E+05	9.28	48.64
4	2.44	5.912E+03	1.473E+04	1.456E+05	9.99	48.73
5	2.91	6.143E+03	1.492E+04	1.503E+05	10.07	48.61
6	3.38	6.209E+03	1.442E+04	1.526E+05	10.58	48.72
7	3.84	6.311E+03	1.431E+04	1.550E+05	10.83	48.72
8	3.37	6.240E+03	1.459E+04	1.519E+05	10.41	48.63
9	3.84	6.326E+03	1.438E+04	1.543E+05	10.73	48.65
10	2.91	6.112E+03	1.472E+04	1.485E+05	10.09	48.74
11	2.44	5.937E+03	1.485E+04	1.430E+05	9.63	48.64
12	1.97	5.729E+03	1.520E+04	1.375E+05	9.05	48.70
13	1.50	5.370E+03	1.525E+04	1.277E+05	8.38	48.69
14	1.03	4.890E+03	1.597E+04	1.152E+05	7.21	48.70

Least-Squares Line for Ho vs q curve:

Slope = -2.6049E-01
 Intercept = 5.8423E+05

Least-squares line for q = a*Δ_l-T^b

a = 2.6230E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHLT1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DREPT

Data taken by : O'KEEFE

This analysis done on file : FONMVHLT2

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.47 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : LPD KORODENSE TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.6588

Alpha (based on Nusselt (Tdel)) = 0.9496

Enhancement (q) = 1.329

Enhancement (Del-T) = 1.238

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.84	6.322E+03	1.446E+04	1.542E+05	10.66	48.63
2	3.37	6.238E+03	1.469E+04	1.519E+05	10.34	48.70
3	2.91	6.078E+03	1.466E+04	1.473E+05	10.05	48.68
4	2.44	5.927E+03	1.495E+04	1.429E+05	9.56	48.68
5	1.97	5.730E+03	1.541E+04	1.371E+05	8.90	48.66
6	1.50	5.388E+03	1.565E+04	1.281E+05	8.18	48.69
7	1.03	4.878E+03	1.622E+04	1.149E+05	7.08	48.65
8	1.97	5.706E+03	1.525E+04	1.377E+05	9.03	48.68
9	2.44	5.941E+03	1.505E+04	1.442E+05	9.58	48.64
10	2.91	6.095E+03	1.477E+04	1.489E+05	10.08	48.69
11	3.94	6.329E+03	1.451E+04	1.554E+05	10.71	48.68
12	1.03	4.891E+03	1.636E+04	1.149E+05	7.02	48.63

Least-Squares Line for Ho vs q curve:

Slope = -2.5633E-01

Intercept = 5.8376E+05

Least-squares line for q = a*delta-T^b

a = 2.6375E+04

b = 7.5000E-01

NOTE: 12 data points were stored in file FONMVHLT2

NOTE: 12 X-Y pairs were stored in data file

NOTE: Program name : DR~~9~~9K
 Data taken by : O'KEEFE
 This analysis done on file : FONMUNLT2
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.47 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : LPD KORODENSE TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.8686
 Alpha (based on Nusselt (Tdel)) = 0.9526
 Enhancement (q) = 1.220
 Enhancement (Del-T) = 1.161

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	1.03	4.198E+03	1.659E+04	1.007E+05	6.07	48.69
2	1.50	4.779E+03	1.625E+04	1.164E+05	7.16	48.67
3	1.97	5.207E+03	1.624E+04	1.296E+05	7.92	48.72
4	2.44	5.441E+03	1.550E+04	1.349E+05	8.70	48.74
5	2.91	5.660E+03	1.532E+04	1.403E+05	9.16	48.68
6	3.38	5.782E+03	1.483E+04	1.432E+05	9.66	48.64
7	3.85	5.873E+03	1.442E+04	1.455E+05	10.08	48.65
8	2.91	5.689E+03	1.552E+04	1.405E+05	9.05	48.72
9	3.85	5.894E+03	1.455E+04	1.462E+05	10.05	48.72
10	2.44	5.475E+03	1.576E+04	1.340E+05	8.51	48.60
11	1.97	5.189E+03	1.604E+04	1.270E+05	7.91	48.70
12	1.03	4.239E+03	1.736E+04	1.013E+05	5.83	48.70

Least-Squares Line for Ho vs q curve:
 Slope = -2.5018E-01
 Intercept = 5.8313E+05

Least-squares line for q = a*delta-T^b
 a = 2.6547E+04
 b = 7.5000E-01

NOTE: 12 data points were stored in file FONMUNLT2

NOTE: 12 X-Y pairs were stored in data file

NOTE: Program name : DREGT
 Data taken by : O'KEEFE
 This analysis done on file : FONMVNLT3
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.47 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : LPD KORODENSE TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.8615
 Alpha (based on Nusselt (Tdel)) = 0.9563
 Enhancement (q) = 1.226
 Enhancement (Del-T) = 1.165

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	1.50	4.781E+03	1.636E+04	1.161E+05	7.10	48.61
2	1.03	4.190E+03	1.678E+04	1.009E+05	6.02	48.64
3	1.50	4.813E+03	1.675E+04	1.177E+05	7.03	48.74
4	1.97	5.180E+03	1.604E+04	1.273E+05	7.93	48.69
5	2.44	5.470E+03	1.578E+04	1.348E+05	8.54	48.63
6	2.91	5.675E+03	1.547E+04	1.408E+05	9.10	48.72
7	3.38	5.781E+03	1.486E+04	1.434E+05	9.65	48.67
8	3.85	5.924E+03	1.477E+04	1.470E+05	9.96	48.69
9	3.38	5.731E+03	1.485E+04	1.433E+05	9.65	48.74
10	3.85	5.881E+03	1.450E+04	1.456E+05	10.04	48.70
11	2.91	5.693E+03	1.558E+04	1.397E+05	8.97	48.65
12	2.44	5.473E+03	1.579E+04	1.340E+05	8.49	48.68
13	1.97	5.198E+03	1.618E+04	1.262E+05	7.80	48.63
14	1.03	4.217E+03	1.717E+04	1.011E+05	5.99	48.67

Least-Squares Line for Ho vs q curve:

Slope = -2.4578E-01

Intercept = 5.8265E+05

Least-squares line for q = a*delta-T^b

a = 2.6648E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVNLT3

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRAGON

Data taken by : O'KEEFE

This analysis done on file : FONMAHLIT1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.47 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.6673

Alpha (based on Nusselt (Tdel)) = 0.8897

Enhancement (q) = 1.211

Enhancement (Del-T) = 1.154

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	2.43	5.447E+03	1.212E+04	3.997E+05	32.98	100.05
2	1.96	5.263E+03	1.230E+04	3.850E+05	31.29	99.98
3	1.50	5.002E+03	1.260E+04	3.649E+05	28.96	99.96
4	1.03	4.605E+03	1.323E+04	3.332E+05	25.19	99.87
5	1.50	4.996E+03	1.257E+04	3.649E+05	29.03	99.98
6	1.03	4.594E+03	1.315E+04	3.334E+05	25.35	99.99
7	1.96	5.251E+03	1.225E+04	3.848E+05	31.42	99.91
8	2.43	5.443E+03	1.211E+04	4.003E+05	33.05	99.98
9	2.90	5.607E+03	1.210E+04	4.124E+05	34.08	100.01
10	3.37	5.698E+03	1.193E+04	4.195E+05	35.16	100.04
11	3.83	5.767E+03	1.178E+04	4.241E+05	35.99	99.96
12	3.37	5.675E+03	1.182E+04	4.170E+05	35.27	100.02
13	3.83	5.767E+03	1.178E+04	4.243E+05	36.00	100.02
14	2.90	5.583E+03	1.198E+04	4.092E+05	34.15	100.01
15	2.43	5.445E+03	1.210E+04	3.983E+05	32.91	100.01

Least-Squares Line for Ho vs q curve:

Slope = -2.4945E-01

Intercept = 7.7129E+05

Least-squares line for q = a*delta-T^b

a = 2.9099E+04

b = 7.5000E-01

NOTE: 15 data points were stored in file FONMAHLIT1

NOTE: 15 X-Y pairs were stored in data file

NOTE: Program name : DRPCRT
 Data taken by : O'KEEFE
 This analysis done on file : FONMANLIT1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.47 (mm)
 Outside diameter, Do = 15.95 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.0362
 Alpha (based on Nusselt (Tdel)) = 0.8688
 Enhancement (q) = 1.184
 Enhancement (Del-T) = 1.135

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.84	5.440E+03	1.152E+04	4.025E+05	34.93	99.97
2	3.37	5.362E+03	1.170E+04	3.954E+05	33.79	99.98
3	2.90	5.285E+03	1.206E+04	3.893E+05	32.28	100.07
4	2.43	5.121E+03	1.220E+04	3.752E+05	30.76	99.85
5	1.96	4.889E+03	1.230E+04	3.571E+05	29.03	99.89
6	1.49	4.591E+03	1.265E+04	3.355E+05	26.52	100.04
7	1.03	4.135E+03	1.324E+04	3.003E+05	22.69	99.96
8	1.50	4.586E+03	1.263E+04	3.359E+05	26.60	100.08
9	1.03	4.132E+03	1.322E+04	3.003E+05	22.71	99.94
10	1.96	4.891E+03	1.234E+04	3.589E+05	29.09	99.90
11	2.43	5.125E+03	1.224E+04	3.774E+05	30.83	99.95
12	2.90	5.247E+03	1.187E+04	3.866E+05	32.58	99.97
13	3.37	5.363E+03	1.171E+04	3.956E+05	33.79	99.94
14	3.84	5.447E+03	1.155E+04	4.017E+05	34.79	99.91

Least-Squares Line for Ho vs q curve:

Slope = -2.5035E-01
 Intercept = 7.6937E+05

Least-squares line for q = a*delta-T^b

a = 2.8535E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANLIT1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DR89T

Data taken by : O'KEEFE

This analysis done on file : FONMVHLIT1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.47 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.3166

Alpha (based on Nusselt (T_{del})) = 0.8799

Enhancement (q) = 1.201

Enhancement (Δ_l-T) = 1.147

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.84	6.001E+03	1.363E+04	1.471E+05	10.80	48.64
2	3.37	5.859E+03	1.355E+04	1.427E+05	10.53	48.66
3	2.91	5.700E+03	1.355E+04	1.390E+05	10.26	48.78
4	2.44	5.510E+03	1.360E+04	1.340E+05	9.85	48.74
5	1.97	5.275E+03	1.378E+04	1.281E+05	9.30	48.81
6	1.50	5.002E+03	1.450E+04	1.195E+05	8.24	48.54
7	1.03	4.510E+03	1.520E+04	1.074E+05	7.07	48.65
8	1.50	4.998E+03	1.448E+04	1.202E+05	8.30	48.59
9	1.03	4.507E+03	1.516E+04	1.079E+05	7.11	48.74
10	1.97	5.292E+03	1.391E+04	1.286E+05	9.24	48.60
11	2.44	5.516E+03	1.366E+04	1.347E+05	9.86	48.57
12	2.91	5.698E+03	1.355E+04	1.400E+05	10.33	48.67
13	3.38	5.863E+03	1.359E+04	1.436E+05	10.57	48.61
14	3.84	5.998E+03	1.361E+04	1.470E+05	10.79	48.59

Least-Squares Line for Ho vs q curve:

Slope = -2.7629E-01

Intercept = 5.8368E+05

Least-squares line for q = a*Δ_l-T^b

a = 2.4437E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHLIT1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DR69t

Data taken by : O'KEEFE
This analysis done on file : FONMUNLIT1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.7837
Alpha (based on Nusselt (Tdel)) = 0.8545
Enhancement (q) = 1.056
Enhancement (Del-T) = 1.041

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.38	5.480E+03	1.334E+04	1.347E+05	10.10	48.60
2	2.91	5.342E+03	1.359E+04	1.305E+05	9.60	48.56
3	2.44	5.123E+03	1.363E+04	1.255E+05	9.21	48.79
4	1.97	4.852E+03	1.377E+04	1.180E+05	8.57	48.73
5	1.50	4.519E+03	1.434E+04	1.093E+05	7.62	48.74
6	1.03	3.996E+03	1.508E+04	9.533E+04	6.35	48.67
7	1.50	4.528E+03	1.447E+04	1.096E+05	7.58	48.60
8	1.03	3.992E+03	1.504E+04	9.598E+04	6.38	48.69
9	1.97	4.854E+03	1.381E+04	1.188E+05	8.60	48.67
10	2.44	5.132E+03	1.371E+04	1.264E+05	9.22	48.74
11	2.91	5.309E+03	1.338E+04	1.307E+05	9.77	48.74
12	3.38	5.470E+03	1.327E+04	1.336E+05	10.07	48.59
13	3.84	5.597E+03	1.317E+04	1.375E+05	10.44	48.70
14	3.37	5.464E+03	1.323E+04	1.338E+05	10.11	48.70
15	3.84	5.589E+03	1.312E+04	1.371E+05	10.46	48.73

Least-Squares Line for Ho vs q curve:

Slope = -2.8007E-01

Intercept = 5.8324E+05

Least-squares line for q = a*delta-T^b

a = 2.3759E+04

b = 7.5000E-01

NOTE: 15 data points were stored in file FONMUNLIT1

NOTE: 15 X-Y pairs were stored in data file

NOTE: Program name : DR004
 Data taken by : O'KEEFE
 This analysis done on file : FONMAHL2T1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.47 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.6388
 Alpha (based on Nusselt (Tdel)) = 0.9089
 Enhancement (q) = 1.246
 Enhancement (Del-T) = 1.179

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.84	5.829E+03	1.210E+04	4.313E+05	35.63	99.96
2	3.37	5.755E+03	1.223E+04	4.238E+05	34.64	99.99
3	2.90	5.641E+03	1.231E+04	4.143E+05	33.64	99.96
4	2.43	5.520E+03	1.255E+04	4.043E+05	32.23	99.99
5	1.96	5.331E+03	1.276E+04	3.892E+05	30.51	99.93
6	1.49	5.020E+03	1.281E+04	3.661E+05	28.58	100.08
7	1.03	4.643E+03	1.369E+04	3.362E+05	24.55	100.01
8	1.50	5.026E+03	1.296E+04	3.667E+05	28.51	99.96
9	1.03	4.622E+03	1.353E+04	3.356E+05	24.81	100.12
10	1.96	5.304E+03	1.261E+04	3.883E+05	30.79	99.96
11	2.43	5.494E+03	1.243E+04	4.030E+05	32.43	99.92
12	2.90	5.640E+03	1.231E+04	4.143E+05	33.66	99.97
13	3.37	5.747E+03	1.219E+04	4.228E+05	34.63	99.99
14	3.83	5.824E+03	1.207E+04	4.290E+05	35.55	100.02

Least-Squares Line for Ho vs q curve:

Slope = -2.4705E-01
 Intercept = 7.7249E+05

Least-squares line for q = a*delta-T^{1.5}b

a = 2.9774E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHL2T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMANL2T1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.47 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.0573
 Alpha (based on Nusselt (Tdel)) = 0.8901
 Enhancement (q) = 1.223
 Enhancement (Del-T) = 1.163

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.84	5.574E+03	1.207E+04	4.108E+05	34.03	99.92
2	3.37	5.450E+03	1.207E+04	4.012E+05	33.25	99.99
3	2.90	5.330E+03	1.222E+04	3.918E+05	32.06	100.00
4	2.43	5.189E+03	1.251E+04	3.811E+05	30.46	100.04
5	1.96	4.967E+03	1.272E+04	3.639E+05	28.61	99.95
6	1.49	4.670E+03	1.313E+04	3.407E+05	25.95	99.94
7	1.03	4.182E+03	1.353E+04	3.038E+05	22.46	100.02
8	1.50	4.663E+03	1.309E+04	3.410E+05	26.04	99.95
9	1.03	4.195E+03	1.369E+04	3.052E+05	22.29	100.00
10	1.96	4.957E+03	1.267E+04	3.650E+05	28.80	100.06
11	2.43	5.165E+03	1.238E+04	3.805E+05	30.73	100.08
12	2.90	5.315E+03	1.215E+04	3.911E+05	32.19	99.93
13	3.37	5.444E+03	1.204E+04	4.019E+05	33.37	100.05
14	3.34	5.552E+03	1.197E+04	4.094E+05	34.20	99.98

Least-Squares Line for Ho vs q curve:

Slope = -2.4184E-01

Intercept = 7.6857E+05

Least-squares line for q = a*delta-T^b

a = 2.9268E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANL2T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRE20E

Data taken by : O'KEEFE

This analysis done on file : FONMVHL2T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.47 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4258

Alpha (based on Nusselt (Tdel)) = 0.8901

Enhancement (q) = 1.220

Enhancement (Del-T) = 1.161

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.85	6.075E+03	1.377E+04	1.517E+05	11.02	48.53
2	3.38	5.908E+03	1.355E+04	1.474E+05	10.87	48.58
3	2.91	5.778E+03	1.368E+04	1.436E+05	10.49	48.68
4	2.44	5.580E+03	1.367E+04	1.385E+05	10.13	48.74
5	1.97	5.372E+03	1.400E+04	1.326E+05	9.47	48.73
6	1.50	5.052E+03	1.432E+04	1.238E+05	8.64	48.71
7	1.03	4.605E+03	1.535E+04	1.113E+05	7.25	48.62
8	1.50	5.045E+03	1.428E+04	1.242E+05	8.70	48.75
9	1.03	4.591E+03	1.521E+04	1.117E+05	7.34	48.70
10	1.97	5.364E+03	1.396E+04	1.331E+05	9.54	48.69
11	2.44	5.596E+03	1.378E+04	1.398E+05	10.14	48.72
12	2.91	5.779E+03	1.370E+04	1.445E+05	10.55	48.65
13	3.38	5.881E+03	1.342E+04	1.475E+05	10.99	48.66
14	3.85	5.989E+03	1.334E+04	1.511E+05	11.33	48.77

Least-Squares Line for Ho vs q curve:

Slope = -2.8095E-01

Intercept = 5.8479E+05

Least-squares line for q = a*delta-T^{nb}

a = 2.4663E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHL2T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE
This analysis done on file : FONMVNL2T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.8387
Alpha (based on Nusselt (Tdel)) = 0.8688
Enhancement (q) = 1.079
Enhancement (Del-T) = 1.059

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.85	5.651E+03	1.326E+04	1.405E+05	10.59	48.72
2	3.38	5.521E+03	1.335E+04	1.373E+05	10.29	48.74
3	2.91	5.371E+03	1.352E+04	1.339E+05	9.90	48.78
4	2.44	5.217E+03	1.400E+04	1.293E+05	9.23	48.65
5	1.97	4.929E+03	1.405E+04	1.225E+05	8.72	48.73
6	1.50	4.582E+03	1.451E+04	1.133E+05	7.81	48.72
7	1.03	4.061E+03	1.530E+04	9.942E+04	6.50	48.66
8	1.50	4.576E+03	1.448E+04	1.142E+05	7.89	48.81
9	1.03	4.043E+03	1.507E+04	9.939E+04	6.59	48.66
10	1.97	4.934E+03	1.412E+04	1.239E+05	8.78	48.73
11	2.44	5.188E+03	1.383E+04	1.302E+05	9.42	48.63
12	2.91	5.379E+03	1.360E+04	1.356E+05	9.97	48.66
13	3.38	5.514E+03	1.334E+04	1.395E+05	10.46	48.75
14	3.85	5.642E+03	1.324E+04	1.418E+05	10.71	48.67

Least-Squares Line for Ho vs q curve:

Slope = -2.7794E-01

Intercept = 5.9363E-05

Least-squares line for q = a*delta-T^b

a = 2.4150E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVNL2T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DR~~0~~KT
 Data taken by : O'KEEFE
 This analysis done on file : FONMAHL3T2
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.47 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.8352
 Alpha (based on Nusselt (T_{del})) = 0.9682
 Enhancement (q) = 1.355
 Enhancement (Del-T) = 1.256

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	1.03	4.880E+03	1.461E+04	3.506E+05	24.00	99.94
2	1.49	5.280E+03	1.378E+04	3.824E+05	27.75	100.01
3	1.96	5.597E+03	1.371E+04	4.070E+05	29.67	100.00
4	2.43	5.783E+03	1.345E+04	4.219E+05	31.35	100.04
5	2.90	5.940E+03	1.337E+04	4.337E+05	32.45	99.99
6	3.36	6.009E+03	1.305E+04	4.397E+05	33.70	100.02
7	3.83	6.100E+03	1.297E+04	4.465E+05	34.42	99.99
8	3.36	6.014E+03	1.307E+04	4.388E+05	33.57	99.90
9	3.83	6.100E+03	1.297E+04	4.460E+05	34.38	99.95
10	2.90	5.939E+03	1.336E+04	4.326E+05	32.39	99.93
11	2.43	5.783E+03	1.344E+04	4.210E+05	31.32	100.07
12	1.96	5.597E+03	1.370E+04	4.050E+05	29.64	100.08
13	1.49	5.278E+03	1.375E+04	3.811E+05	27.73	100.04
14	1.03	4.883E+03	1.459E+04	3.492E+05	23.93	99.96

Least-Squares Line for Ho vs q curve:

Slope = -2.2528E-01
 Intercept = 7.6980E+05

Least-squares line for q = a*delta-T^b

a = 3.1776E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHL3T2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRP94T

Data taken by : O'KEEFE
This analysis done on file : FONMANL3T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.2023
Alpha (based on Nusselt (Tdel)) = 0.9330
Enhancement (q) = 1.302
Enhancement (Del-T) = 1.219

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.83	5.767E+03	1.262E+04	4.229E+05	33.50	99.98
2	3.36	5.682E+03	1.279E+04	4.139E+05	32.36	99.92
3	2.90	5.564E+03	1.297E+04	4.050E+05	31.23	100.07
4	2.43	5.398E+03	1.312E+04	3.908E+05	29.79	99.90
5	1.96	5.197E+03	1.348E+04	3.759E+05	27.89	100.00
6	1.49	4.867E+03	1.370E+04	3.519E+05	25.69	100.12
7	1.03	4.390E+03	1.429E+04	3.154E+05	22.09	100.03
8	1.49	4.877E+03	1.380E+04	3.523E+05	25.53	99.90
9	1.03	4.398E+03	1.438E+04	3.160E+05	21.97	99.95
10	1.96	5.189E+03	1.344E+04	3.763E+05	28.00	99.96
11	2.43	5.394E+03	1.311E+04	3.924E+05	29.93	100.02
12	2.90	5.558E+03	1.294E+04	4.045E+05	31.25	99.91
13	3.36	5.663E+03	1.269E+04	4.127E+05	32.51	99.87
14	3.83	5.776E+03	1.265E+04	4.211E+05	33.30	100.01

Least-Squares Line for Ho vs q curve:

Slope = -2.2955E-01

Intercept = 7.5779E+05

Least-squares line for q = a*delta-T^b

a = 3.0712E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANL3T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVHL3T1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.47 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.6094

Alpha (based on Nusselt (T_{del})) = 0.9949

Enhancement (q) = 1.415

Enhancement (Δ_l-T) = 1.297

Data #	U _w (m/s)	U _o (W/m ² -K)	Ho (W/m ² -K)	Q _p (W/m ²)	T _{cf} (C)	T _s (C)
1	3.84	6.544E+03	1.581E+04	1.570E+05	9.93	48.61
2	3.37	6.381E+03	1.565E+04	1.526E+05	9.75	48.70
3	2.90	6.240E+03	1.580E+04	1.481E+05	9.38	48.68
4	2.43	6.057E+03	1.598E+04	1.425E+05	8.91	48.60
5	1.97	5.839E+03	1.645E+04	1.370E+05	8.33	48.69
6	1.50	5.451E+03	1.649E+04	1.268E+05	7.69	48.65
7	1.03	4.959E+03	1.761E+04	1.151E+05	6.54	48.75
8	1.50	5.441E+03	1.642E+04	1.271E+05	7.74	48.62
9	1.03	4.961E+03	1.764E+04	1.146E+05	6.50	48.63
10	1.97	5.781E+03	1.603E+04	1.367E+05	8.53	48.65
11	2.43	6.023E+03	1.577E+04	1.431E+05	9.07	48.62
12	2.90	6.221E+03	1.568E+04	1.483E+05	9.45	48.65
13	3.37	6.393E+03	1.572E+04	1.529E+05	9.73	48.67
14	3.84	6.490E+03	1.549E+04	1.554E+05	10.03	48.74

Least-Squares Line for Ho vs q curve:

Slope = -2.3649E-01

Intercept = 5.8263E+05

Least-squares line for q = a*Δ_l-T^b

a = 2.7690E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHL3T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : D'KEEFE
 This analysis done on file : FONMVNL3T1
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.47 (mm)
 Outside diameter, Do = 15.85 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

C_i (based on Petukhov-Popov) = 2.0410
 Alpha (based on Nusselt (T_{del})) = 0.9419
 Enhancement (q) = 1.202
 Enhancement (Δ_i-T) = 1.148

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	T _{cf} (C)	T _s (C)
1	3.37	5.954E+03	1.506E+04	1.439E+05	9.55	48.73
2	3.84	6.043E+03	1.469E+04	1.462E+05	9.95	48.77
3	3.37	5.937E+03	1.494E+04	1.424E+05	9.53	48.67
4	3.84	6.031E+03	1.461E+04	1.443E+05	9.87	48.59
5	2.90	5.754E+03	1.493E+04	1.373E+05	9.20	48.68
6	2.43	5.565E+03	1.523E+04	1.330E+05	8.73	48.74
7	1.97	5.292E+03	1.543E+04	1.254E+05	8.13	48.69
8	1.50	4.917E+03	1.576E+04	1.158E+05	7.35	48.68
9	1.03	4.397E+03	1.686E+04	1.032E+05	6.12	48.73
10	1.50	4.940E+03	1.602E+04	1.172E+05	7.31	48.72
11	1.03	4.393E+03	1.682E+04	1.032E+05	6.13	48.72
12	1.97	5.295E+03	1.548E+04	1.265E+05	8.17	48.67
13	2.44	5.561E+03	1.522E+04	1.334E+05	8.77	48.61
14	2.90	5.771E+03	1.507E+04	1.388E+05	9.21	48.66

Least-Squares Line for Ho vs q curve:
 Slope = -2.5211E-01
 Intercept = 5.8301E+05

Least-squares line for q = a*Δ_i-T^b
 a = 2.6202E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVNL3T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRAGON

821
Data taken by : O'KEEFE

This analysis done on file : FONMAHC1

This analysis includes end-fin effect

Thermal conductivity = 385.0 (W/m.K)

Inside diameter, Di = 12.70 (mm)

Outside diameter, Do = 19.05 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : COPPER

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.9086

Alpha (based on Nusselt (Tdel)) = 0.6318

Enhancement (q) = 1.049

Enhancement (Del-T) = 1.037

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.31	6.736E+03	9.034E+03	4.860E+05	53.80	99.89
2	3.78	6.667E+03	9.157E+03	4.792E+05	52.33	100.04
3	3.25	6.574E+03	9.307E+03	4.697E+05	50.47	100.02
4	2.73	6.427E+03	9.463E+03	4.576E+05	48.35	99.97
5	2.20	6.207E+03	9.636E+03	4.405E+05	45.72	99.99
6	1.68	5.880E+03	9.868E+03	4.160E+05	42.16	100.03
7	1.15	5.439E+03	1.049E+04	3.803E+05	36.24	99.99
8	4.30	6.655E+03	9.234E+03	4.898E+05	53.04	99.94
9	3.77	6.765E+03	9.358E+03	4.794E+05	51.23	99.88
10	3.25	6.684E+03	9.498E+03	4.689E+05	49.37	99.96
11	2.72	6.501E+03	9.564E+03	4.541E+05	47.39	100.03
12	2.20	6.290E+03	9.787E+03	4.380E+05	44.75	100.11
13	1.67	5.971E+03	1.005E+04	4.128E+05	41.07	100.05
14	1.15	5.504E+03	1.065E+04	3.783E+05	35.53	100.04
15	2.20	6.310E+03	9.845E+03	4.402E+05	44.72	99.94
16	3.25	6.682E+03	9.491E+03	4.686E+05	49.37	100.05
17	4.29	6.869E+03	9.235E+03	4.826E+05	52.26	100.10

Least-Squares Line for Ho vs q curve:

Slope = -3.4908E-01

Intercept = 7.5868E+05

Least-squares line for q = a*delta-T^b

a = 2.5131E+04

b = 7.5000E-01

NOTE: 17 data points were stored in file FONMAHC1

NOTE: 17 X-Y pairs were stored in data file

NOTE: Program name : D820K
 Data taken by : O'KEEFE
 This analysis done on file : FONMANC1
 This analysis includes end-fin effect
 Thermal conductivity = 385.0 (W/m.K)
 Inside diameter, Di = 12.70 (mm)
 Outside diameter, Do = 19.05 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : COPPER
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.2653
 Alpha (based on Nusselt (Tdel)) = 0.8158
 Enhancement (q) = 1.052
 Enhancement (Del-T) = 1.039

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tof (C)	Ts (C)
1	4.31	5.764E+03	9.703E+03	4.227E+05	43.56	99.92
2	3.79	5.643E+03	9.971E+03	4.120E+05	41.32	99.98
3	3.26	5.366E+03	9.971E+03	3.929E+05	39.40	100.05
4	2.73	5.144E+03	1.024E+04	3.749E+05	36.60	99.99
5	2.21	4.827E+03	1.058E+04	3.505E+05	33.13	99.92
6	1.68	4.341E+03	1.073E+04	3.157E+05	29.42	100.02
7	1.16	3.805E+03	1.203E+04	2.757E+05	22.92	100.02
8	1.68	4.344E+03	1.079E+04	3.172E+05	29.41	100.00
9	1.16	3.804E+03	1.205E+04	2.757E+05	22.89	99.94
10	2.21	4.812E+03	1.055E+04	3.521E+05	33.36	100.00
11	2.73	5.157E+03	1.031E+04	3.772E+05	36.57	99.96
12	3.26	5.374E+03	9.959E+03	3.939E+05	39.56	99.97
13	3.79	5.643E+03	9.988E+03	4.137E+05	41.41	99.96
14	4.31	5.762E+03	9.693E+03	4.224E+05	43.58	99.96

Least-Squares Line for Ho vs q curve:

Slope = -2.8166E-01

Intercept = 7.2938E+05

Least-squares line for q = a*delta-T^b

a = 2.5317E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANC1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRFOBT
 Data taken by : O'KEEFE
 This analysis done on file : FONMUHC1
 This analysis includes end-fin effect
 Thermal conductivity = 365.0 (W/m.K)
 Inside diameter, Di = 12.70 (mm)
 Outside diameter, Do = 19.05 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : COPPER
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4815
 Alpha (based on Nusselt (Tdel)) = 0.8379
 Enhancement (q) = .958
 Enhancement (Del-T) = .963

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	4.32	7.579E+03	1.110E+04	1.749E+05	15.75	48.74
2	3.79	7.327E+03	1.098E+04	1.683E+05	15.32	48.69
3	3.26	7.140E+03	1.110E+04	1.631E+05	14.69	48.63
4	2.74	6.907E+03	1.128E+04	1.575E+05	13.96	48.63
5	2.21	6.573E+03	1.144E+04	1.492E+05	13.04	48.63
6	1.68	6.158E+03	1.185E+04	1.399E+05	11.81	48.72
7	1.16	5.538E+03	1.291E+04	1.248E+05	9.90	48.73

Least-Squares Line for Ho vs q curve:

Slope = -3.2813E-01

Intercept = 5.5448E+05

Least-squares line for q = a*delta-T^{1/4}b

a = 2.1921E+04

b = 7.5000E-01

NOTE: 07 data points were stored in file FONMUHC1

NOTE: 07 X-Y pairs were stored in data file

NOTE: Program name : DRIFT

Data taken by : O'KEEFE

This analysis done on file : FONMUNC1

This analysis includes end-fin effect

Thermal conductivity = 385.0 (W/m.K)

Inside diameter, Di = 12.70 (mm)

Outside diameter, Do = 19.05 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : COPPER

Pressure condition : VACUUM

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.0847

Alpha (based on Nusselt (Tdel)) = 0.8663

Enhancement (q) = .942

Enhancement (Del-T) = .956

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Gp (W/m ³)	Tcf (C)	Ts (C)
1	4.32	6.182E+03	1.238E+04	1.461E+05	11.80	48.53
2	3.79	5.937E+03	1.255E+04	1.401E+05	11.16	48.64
3	3.27	5.646E+03	1.277E+04	1.336E+05	10.48	48.77
4	2.74	5.290E+03	1.301E+04	1.252E+05	9.53	48.78
5	2.21	4.865E+03	1.339E+04	1.144E+05	8.54	48.71
6	1.68	4.309E+03	1.379E+04	1.009E+05	7.32	48.64
7	1.16	3.641E+03	1.540E+04	8.492E+04	5.51	48.62
8	1.68	4.323E+03	1.399E+04	1.023E+05	7.31	48.67
9	1.16	3.637E+03	1.533E+04	9.518E+04	5.56	48.73
10	2.21	4.811E+03	1.306E+04	1.151E+05	8.92	48.74
11	2.74	5.290E+03	1.305E+04	1.264E+05	9.68	48.69
12	3.27	5.637E+03	1.276E+04	1.353E+05	10.60	48.75
13	3.79	5.915E+03	1.248E+04	1.408E+05	11.29	48.69
14	4.32	6.186E+03	1.240E+04	1.470E+05	11.85	48.64

Least-Squares Line for Ho vs q curve:

Slope = -2.7240E-01

Intercept = 5.4643E+05

Least-squares line for q = a+delta-T^{1/4}b

a = 2.2994E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMUNC1

NOTE: 14 K-T pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAH68C1
 This analysis includes end-fin effect
 Thermal conductivity = 385.0 (W/m.K)
 Inside diameter, Di = 12.70 (mm)
 Outside diameter, Do = 19.05 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : COPPER
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.8065
 Alpha (based on Nusselt (Tdel)) = 1.2643
 Enhancement (q) = 1.934
 Enhancement (Del-T) = 1.640

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tof (C)	Ts (C)
1	4.29	9.492E+03	1.466E+04	6.577E+05	44.87	100.04
2	3.76	9.328E+03	1.488E+04	6.388E+05	42.93	99.97
3	3.24	9.132E+03	1.522E+04	6.213E+05	40.83	99.96
4	2.72	8.827E+03	1.553E+04	5.975E+05	38.48	99.92
5	2.19	8.375E+03	1.581E+04	5.666E+05	35.84	100.01
6	1.67	7.795E+03	1.637E+04	5.249E+05	32.06	100.02
7	1.15	6.985E+03	1.771E+04	4.679E+05	26.42	100.07
8	1.67	7.804E+03	1.647E+04	5.292E+05	32.13	100.00
9	1.15	6.992E+03	1.776E+04	4.684E+05	26.37	100.08
10	2.20	8.478E+03	1.623E+04	5.785E+05	35.64	100.01
11	2.72	8.949E+03	1.593E+04	6.088E+05	38.21	99.92
12	3.24	9.264E+03	1.559E+04	6.313E+05	40.50	100.01
13	3.76	9.531E+03	1.537E+04	6.466E+05	42.06	99.95
14	4.28	9.743E+03	1.520E+04	6.612E+05	43.50	99.97

Least-Squares Line for Ho vs q curve:
 Slope = -1.9114E-01
 Intercept = 7.3487E+05

Least-squares line for q = a*delta-T^b
 a = 3.9079E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH68C1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAN68C1

This analysis includes end-fin effect

Thermal conductivity = 385.0 (W/m.K)

Inside diameter, Di = 12.70 (mm)

Outside diameter, Do = 19.05 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : COPPER

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.2431

Alpha (based on Nusselt (Tdel)) = 1.3159

Enhancement (q) = 2.059

Enhancement (Del-T) = 1.719

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	4.29	7.797E+03	1.712E+04	5.462E+05	31.90	100.00
2	3.77	7.478E+03	1.747E+04	5.242E+05	30.00	100.03
3	3.25	7.128E+03	1.807E+04	4.989E+05	27.61	99.95
4	2.72	6.596E+03	1.812E+04	4.635E+05	25.58	99.99
5	2.20	5.980E+03	1.823E+04	4.200E+05	23.05	100.02
6	1.68	5.287E+03	1.914E+04	3.723E+05	19.45	100.04
7	1.15	4.502E+03	2.354E+04	3.170E+05	13.47	100.10
8	1.68	5.263E+03	1.901E+04	3.730E+05	19.62	100.01
9	1.15	4.450E+03	2.252E+04	3.153E+05	14.00	100.04
10	2.20	6.006E+03	1.874E+04	4.275E+05	22.81	99.95
11	2.73	6.655E+03	1.877E+04	4.724E+05	25.17	99.88
12	3.25	7.209E+03	1.878E+04	5.113E+05	27.23	99.99
13	3.77	7.658E+03	1.862E+04	5.423E+05	29.12	99.87
14	4.30	8.034E+03	1.837E+04	5.663E+05	30.83	100.00

Least-Squares Line for Ho vs q curve:

Slope = -1.3433E-01

Intercept = 7.1006E+05

Least-squares line for q = a*delta-T^b

a = 4.1757E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN68C1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVH68C1

This analysis includes end-fin effect

Thermal conductivity = 385.0 (W/m.K)

Inside diameter, Di = 12.70 (mm)

Outside diameter, Do = 19.05 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : COPPER

Pressure condition : VACUUM

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.5490

Alpha (based on Nusselt (Tdel)) = 1.1854

Enhancement (q) = 1.787

Enhancement (Del-T) = 1.546

Data #	Uw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.32	9.811E+03	1.641E+04	2.246E+05	13.69	48.74
2	3.79	9.448E+03	1.628E+04	2.148E+05	13.19	48.81
3	3.26	9.165E+03	1.658E+04	2.062E+05	12.43	48.78
4	2.73	8.699E+03	1.660E+04	1.946E+05	11.72	48.77
5	2.21	8.209E+03	1.703E+04	1.826E+05	10.72	48.72
6	1.68	7.523E+03	1.755E+04	1.668E+05	9.51	48.76
7	1.15	6.670E+03	1.944E+04	1.451E+05	7.46	48.62
8	1.68	7.515E+03	1.754E+04	1.687E+05	9.62	48.81
9	1.15	6.668E+03	1.948E+04	1.455E+05	7.48	48.55
10	2.21	8.220E+03	1.713E+04	1.848E+05	10.79	48.53
11	2.74	8.740E+03	1.678E+04	1.968E+05	11.73	48.59
12	3.26	9.189E+03	1.668E+04	2.073E+05	12.43	48.63
13	3.79	9.446E+03	1.627E+04	2.139E+05	13.15	48.74
14	4.31	9.846E+03	1.649E+04	2.212E+05	13.42	48.60

Least-Squares Line for Ho vs q curve:

Slope = -2.0791E-01

Intercept = 5.4980E+05

Least-squares line for q = a*delta-T^b

a = 3.1228E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH68C1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVN58C1

This analysis includes end-fin effect

Thermal conductivity = 385.0 (W/m.K)

Inside diameter, Di = 12.70 (mm)

Outside diameter, Do = 19.05 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : COPPER

Pressure condition : VACUUM

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0378

Alpha (based on Nusselt (Tdel)) = 1.2885

Enhancement (q) = 1.825

Enhancement (Del-T) = 1.570

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.32	7.410E+03	1.958E+04	1.749E+05	8.93	48.82
2	3.79	7.037E+03	1.994E+04	1.644E+05	8.24	48.70
3	3.26	6.671E+03	2.102E+04	1.549E+05	7.37	48.66
4	2.74	6.177E+03	2.189E+04	1.432E+05	6.54	48.63
5	2.21	5.557E+03	2.262E+04	1.288E+05	5.69	48.61
6	1.68	4.800E+03	2.340E+04	1.111E+05	4.75	48.60
7	1.16	3.882E+03	2.496E+04	8.997E+04	3.60	48.78
8	1.68	4.765E+03	2.277E+04	1.127E+05	4.95	48.81
9	1.16	3.877E+03	2.492E+04	8.988E+04	3.61	48.63
10	2.21	5.572E+03	2.308E+04	1.316E+05	5.70	48.67
11	2.74	6.155E+03	2.177E+04	1.446E+05	6.64	48.55
12	3.27	6.643E+03	2.086E+04	1.567E+05	7.51	48.66
13	3.79	7.016E+03	1.981E+04	1.647E+05	8.31	48.67
14	4.32	7.407E+03	1.954E+04	1.746E+05	8.94	48.85
15	2.74	6.165E+03	2.172E+04	1.423E+05	6.55	48.58
16	1.16	3.896E+03	2.523E+04	8.882E+04	3.52	48.70

Least-Squares Line for Ho vs q curve:

Slope = -1.6323E-01

Intercept = 5.4549E+05

Least-squares line for q = a*delta-T^b

a = 3.4454E+04

b = 7.5000E-01

NOTE: 16 data points were stored in file FONMVN58C1

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAH7101
 This analysis includes end-fin effect
 Thermal conductivity = 385.0 (W/m.K)
 Inside diameter, Di = 12.70 (mm)
 Outside diameter, Do = 19.05 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using HEATEX insert inside tube
 Tube Enhancement : SMOOTH TUBE
 Tube material : COPPER
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 3.0634
 Alpha (based on Nusselt (T_{del})) = 1.5049
 Enhancement (q) = 2.313
 Enhancement (Δ_l-T) = 1.875

Data #	U _w (m/s)	U _o (W/m ² -K)	Ho (W/m ² -K)	Q _p (W/m ²)	T _{cf} (C)	T _s (C)
1	4.29	1.097E+04	1.770E+04	7.469E+05	42.20	99.96
2	3.76	1.075E+04	1.796E+04	7.258E+05	40.42	99.96
3	3.24	1.050E+04	1.835E+04	7.052E+05	38.42	99.99
4	2.72	1.007E+04	1.860E+04	6.764E+05	36.37	99.97
5	2.19	9.574E+03	1.911E+04	6.407E+05	33.53	99.94
6	1.67	8.871E+03	1.986E+04	5.945E+05	29.94	100.00
7	1.15	7.842E+03	2.121E+04	5.237E+05	24.63	99.94
8	1.67	8.896E+03	2.011E+04	6.029E+05	29.97	99.92
9	1.15	7.902E+03	2.174E+04	5.310E+05	24.43	100.03
10	2.20	9.801E+03	2.017E+04	6.671E+05	33.06	100.00
11	2.72	1.039E+04	1.979E+04	7.079E+05	35.77	99.96
12	3.24	1.090E+04	1.970E+04	7.425E+05	37.63	100.07

Least-Squares Line for Ho vs q curve:
 Slope = -1.4745E-01
 Intercept = 7.2637E+05

Least-squares line for q = a*Δ_l-T^b
 a = 4.6853E+04
 b = 7.5000E-01

NOTE: 12 data points were stored in file FONMAH7101

NOTE: 12 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAN7101

This analysis includes end-fin effect

Thermal conductivity = 385.0 (W/m.K)

Inside diameter, Di = 12.70 (mm)

Outside diameter, Do = 19.05 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : COPPER

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C_f (based on Petukhov-Popov) = 1.2503

Alpha (based on Nusselt (T_{del})) = 1.7215

Enhancement (q) = 2.847

Enhancement (Δ_f-T) = 2.132

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	T _{of} (C)	T _s (C)
1	4.29	8.928E+03	2.330E+04	6.214E+05	25.67	99.87
2	3.77	8.523E+03	2.393E+04	5.928E+05	24.77	100.01
3	3.25	8.042E+03	2.471E+04	5.581E+05	22.53	99.93
4	2.72	7.374E+03	2.471E+04	5.131E+05	20.77	99.94
5	2.20	6.613E+03	2.490E+04	4.625E+05	18.57	100.05
6	1.68	5.750E+03	2.532E+04	4.028E+05	15.54	99.99
7	1.15	4.766E+03	3.095E+04	3.333E+05	10.77	99.95
8	1.68	5.724E+03	2.502E+04	4.054E+05	15.70	100.09
9	1.15	4.874E+03	3.643E+04	3.424E+05	9.40	100.10
10	2.20	6.650E+03	2.605E+04	4.720E+05	13.12	100.04
11	2.73	7.500E+03	2.659E+04	5.292E+05	19.90	100.03
12	3.25	8.213E+03	2.671E+04	5.778E+05	21.64	100.10
13	3.77	8.881E+03	2.713E+04	6.202E+05	22.86	99.99
14	4.29	9.435E+03	2.704E+04	6.561E+05	24.27	99.99

Least-Squares Line for Ho vs q curve:

Slope = -8.8527E-02

Intercept = 7.0340E+05

Least-squares line for q = a+Δ_f-T^{1/4}b

a = 5.5135E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN7101

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVN7101
 This analysis includes end-fin effect
 Thermal conductivity = 385.0 (W/m.K)
 Inside diameter, Di = 12.70 (mm)
 Outside diameter, Do = 19.05 (mm)
 This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
 Using no insert inside tube
 Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
 Tube material : COPPER
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.0883
 Alpha (based on Nusselt (Tdel)) = 1.4135
 Enhancement (q) = 1.809
 Enhancement (Del-T) = 1.560

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Op (W/m ²)	Tcf (C)	Ts (C)
1	4.32	7.865E+03	2.150E+04	1.844E+05	8.58	48.59
2	3.79	7.432E+03	2.168E+04	1.751E+05	8.07	48.74
3	3.26	7.045E+03	2.292E+04	1.647E+05	7.18	48.71
4	2.74	6.532E+03	2.410E+04	1.529E+05	6.35	48.78
5	2.21	5.872E+03	2.512E+04	1.376E+05	5.48	48.63
6	1.68	5.029E+03	2.523E+04	1.187E+05	4.70	48.74
7	1.16	4.068E+03	2.738E+04	9.574E+04	3.50	48.73
8	1.68	5.056E+03	2.616E+04	1.204E+05	4.60	48.69
9	1.16	4.073E+03	2.775E+04	9.599E+04	3.46	48.86
10	2.21	5.881E+03	2.559E+04	1.402E+05	5.48	48.58
11	2.74	6.521E+03	2.427E+04	1.563E+05	6.44	48.67
12	3.27	7.074E+03	2.350E+04	1.693E+05	7.21	48.61
13	3.79	7.497E+03	2.238E+04	1.802E+05	8.05	48.92
14	4.32	7.370E+03	2.160E+04	1.882E+05	8.71	48.63

Least-Squares Line for Ho vs q curve:

Slope = -1.4850E-01

Intercept = 5.4553E+05

Least-squares line for q = a+delta-T^{0.5}b

a = 3.7811E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN7101

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVH71C2

This analysis includes end-fin effect

Thermal conductivity = 385.0 (W/m.K)

Inside diameter, Di = 12.70 (mm)

Outside diameter, Do = 19.05 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE

Tube material : COPPER

Pressure condition : VACUUM

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.7647

Alpha (based on Nusselt (Tdel)) = 1.2803

Enhancement (q) = 1.686

Enhancement (Del-T) = 1.479

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	1.16	7.118E+03	2.072E+04	1.563E+05	7.64	48.64
2	1.68	8.035E+03	1.882E+04	1.832E+05	9.73	48.77
3	2.21	8.775E+03	1.833E+04	2.015E+05	10.99	48.69
4	2.74	9.287E+03	1.784E+04	2.147E+05	12.03	48.73
5	3.26	9.855E+03	1.805E+04	2.262E+05	12.53	48.55
6	3.79	1.015E+04	1.766E+04	2.354E+05	13.33	48.75
7	4.32	1.038E+04	1.736E+04	2.413E+05	13.90	48.79
8	3.26	9.850E+03	1.802E+04	2.245E+05	12.46	48.60
9	2.21	8.857E+03	1.865E+04	1.992E+05	10.66	48.55
10	1.16	7.142E+03	2.088E+04	1.571E+05	7.53	48.57

Least-Squares Line for Ho vs q curve:

Slope = -1.9477E-01

Intercept = 5.5020E+05

Least-squares line for q = a*delta-T^b

a = 3.3765E+04

b = 7.5000E-01

NOTE: 10 data points were stored in file FONMVH71C2

NOTE: 10 X-Y pairs were stored in data file

APPENDIX E. DRPOK PROGRAM LISTING

The program DRPOK, which was used to collect and reprocess all of the data, is listed in this appendix.

```

100! DRPOK (O'KEEFE)
106! REVISED FROM DRP12B: JUL 1992 (S. MEMORY)
107!
108! TO BE USED WITH NON-INSTRUMENTED TUBES ONLY
109! TAKES DATA IN THE FORMAT OF SWENSEN/O'KEEFE
110! CAN REPROCESS ANY NON-INSTRUMENTED DATA
112!
113! THIS PROGRAM WAS USED TO COLLECT ALL THE NON-
114! INSTRUMENTED DATA TAKEN BY O'KEEFE (APR-SEP 1992) FOR TITANIUM TUBES
115!
117! MEANING OF ALL FLAGS IN PROGRAM
118!
119! IFT: FLUID TYPE
120! ISO: OPTION WITHIN PROGRAM
121! IM: INPUT MODE
122! IWIL: VALUE OF Ci USED
123! IFG: FINNED OR SMOOTH
124! INN: INSERT TYPE
125! IWT: LOOP NO. WITHIN PROGRAM
126! IWTH: ALTERNATIVE CONDENSER TUBES
127! IMC: TUBE MATERIAL
128! ITDS: TUBE DIAMETER
129! IPC: PRESSURE CONDITION
130! INF: DIMENSIONLESS FILE REQUIRED
131! IPF: PLOT FILE REQUIRED
132! IOV: OUTPUT REQUIRED
133! IHI: INSIDE HTC CORRELATION
134! IOC: OUTSIDE HTC THEORY/CORRELATION
135 COM /Cc/ C(7)
136 COM /Cc55/ T55(5)
137 COM /Cc56/ T56(5)
138 COM /Cc57/ T57(5)
139 COM /Cc58/ T58(5)
140 COM /Fld/ Ift,Istu
141 DIM Emf(20),Tw(6)
142 COM /Pr/ Qpa(20),Tfm(20),Tfmr,Ipc,Qpr
143 COM /Wil/ Nrun,Itm,Iwth,Imc,Ife,Ijob,Iwd,Ifg,Ipc,Ifto,Iwil,Ihi,Ioc,Inam,t
u,Rep,Rm
144 COM /Geom/ D1,D2,D1,Do,L,L1,L2
146 DATA 0.10086091,25727.94369,-767345.8295,78025595.81
147 DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
148 READ C(*)
149 DATA 273.15,2.5943E-2,-7.2671E-7,3.2941E-11,-9.7719E-16,9.7121E-20
150 READ T55(*)
151 DATA 273.15,2.5878E-2,-5.9853E-7,-3.1242E-11,1.3275E-14,-1.0186E-18
152 READ T56(*)
153 DATA 273.15,2.5923E-2,-7.3933E-7,2.8625E-11,1.9717E-15,-2.2486E-19

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1054 READ T57(*)
1055 DATA 273.15,2.5931E-2,-7.5232E-7,4.0657E-11,-1.2791E-15,6.4402E-20
1056 READ T58(*)
1057 Dr=.015875 ! Outside diameter of the outlet end
1058 Dssp=.1524 ! Inside diameter of stainless steel test section
1059 As=PI*Dssp2/4
1060 Alp2=0.
1061 L=.13335 ! Condensing length
1062 L1=.060325 ! Inlet end "fin length"
1063 L2=.034925 ! Outlet end "fin length"
1064 PRINTER IS 1
1065 BEEP
1066 PRINT USING "4X","Select option:"""
1069 PRINT USING "6X"," 0 Take data or re-process previous data""
1084 PRINT USING "6X"," 1 Print raw data""
1090 PRINT USING "6X"," 2 WILSON Analysys""
1093 PRINT USING "6X"," 3 MODIFY""
1096 PRINT USING "6X"," 4 PURGE""
1102 PRINT USING "6X"," 5 RENAME""
1105 INPUT Iso
1108 Iso=Iso+1
1111 IF Iso=1 THEN 3094
1112 BEEP
1115 INPUT "SELECT FLUID (0=WATER, 1=R-113, 2=EG)",Ift
1116 Ifto=Ift
1117 BEEP
1118 Ijob=0
1119 INPUT "ENTER INPUT MODE (0=3054A,1=FILE)",Im
1120 Im=Im+1
1123 BEEP
1124 IF Im=1 THEN
1126 INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
1129 OUTPUT 709;"TD";Date$
1132 OUTPUT 709;"TD"
1133 ENTER 709;Date$
1135 END IF
1136 IF Ijob=1 THEN
1138 BEEP
1141 INPUT "SKIP PAGE AND HIT ENTER",OI
1144 END IF
1145 PRINTER IS 701
1146 IF Im=1 THEN
1148 ENTER 709;Date$
1150 PRINT " Month, date and time :";Date$
1151 END IF
1153 PRINT

```

```

156 PRINT USING "10X","NOTE: Program name : DRPOK""
171 IF Ijob=1 THEN 1189
174 BEEP
186 INPUT "SELECT (C1:0=FINNED,1=STORED C1)",Iw1
189 IF Im=1 THEN
192 BEEP
195 INPUT "GIVE A NAME FOR THE RAW DATA FILE",D_file$
198 PRINT USING "16X","File name      : ",14A";D_file$
201 CREATE BDAT D_file$,30
204 ASSIGN @File TO D_file$
207 BEEP
210 INPUT "ENTER GEOMETRY CODE (1=FINNED,0=PLAIN)",Ifg
211 Inn=0
212 PRINTER IS 1
216 BEEP
217 PRINT "    ENTER INSERT TYPE:"
218 PRINT "        0=NONE (DEFAULT)"
219 PRINT "        1=TWISTED TAPE"
220 PRINT "        2=WIRE WRAP"
221 PRINT "        3=HEATEX"
222 INPUT Inn
226 OUTPUT @File;Ifg,Inn
227 Iwt=0 ! FOR UNINSTRUMENTED TUBE
228 Fh=0
231 Fp=0
234 Fw=0
235 Istu=0
237 IF Ifg=0 THEN 1241
238 INPUT "FIN PITCH, HEIGHT AND WIDTH, Fp,Fh,Fw",Fp,Fh,Fw
241 OUTPUT @File;Iwt,Fp,Fw,Fh
242 ELSE
249 BEEP
250 PRINTER IS 1
252 PRINT "    STUDENT'S DATA TO BE REPROCESSED:"
253 PRINT "        0=SWENSEN/O'KEEFE (DEFAULT)"
254 PRINT "        1=VAN PETTEN/MITROU/COUMES/GUTTENDORF"
255 INPUT Istu
256 BEEP
257 PRINT
259 IF Istu=1 THEN
260 PRINT "    STUDENT NAME:"
261 PRINT "        0=VAN PETTEN"
262 PRINT "        1=MITROU"
263 PRINT "        2=COUMES"
264 PRINT "        3=GUTTENDORF"
265 ELSE

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```

1267 PRINT " 4=SWENSEN"
1268 PRINT " 5=O'KEEFE"
1271 END IF
1272 INPUT Inam
1273 BEEP
1274 INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D_file$
1275 PRINTER IS 701
1276 IF Inam=0 THEN PRINT USING "16X,""Data taken by : VAN PETTEN
""
1277 IF Inam=1 THEN PRINT USING "16X,""Data taken by : MITROU""
1278 IF Inam=2 THEN PRINT USING "16X,""Data taken by : COUMES""
1279 IF Inam=3 THEN PRINT USING "16X,""Data taken by : GUTTENDORF
""
1280 IF Inam=4 THEN PRINT USING "16X,""Data taken by : SWENSEN""
1281 IF Inam=5 THEN PRINT USING "16X,""Data taken by : O'KEEFE""
1282 PRINT USING "16X,""This analysis done on file : "",10A";D_file$
1283 PRINTER IS 1
1285 BEEP
1286 INPUT "ENTER NUMBER OF DATA SETS STORED",Nrun
1287 ASSIGN @File TO D_file$
1288 ENTER @File;Ifg,Inn
1289 IF Istu=0 THEN
1290 ENTER @File;Iwt,Fp,Fw,Fh
1291 ELSE
1292 IF Ifg=0 THEN ENTER @File;Iwt
1293 IF Ifg=1 THEN ENTER @File;Fp,Fw,Fh
1294 END IF
1295 END IF
1296 IF Ijob=1 THEN 1537
1297 IF Ift=0 THEN 1345
1298 BEEP
1299 PRINTER IS 1
1300 PRINT USING "4X,""Select tube type: ""
1301 PRINT USING "6X,""0 Thick wall Copper ""
1306 PRINT USING "6X,""1 Wolverine Korodense LPD Titanium Tube ""
1320 PRINT USING "6X,""2 Smooth Titanium Tube ""
1321 INPUT Iwth
1322 BEEP
1324 PRINT USING "4X,""Select tube Enhancement used: ""
1325 PRINT USING "6X,""0 SMOOTH TUBE ""
1326 PRINT USING "6X,""1 FINNED TUBE ""
1327 PRINT USING "6X,""2 WIRE-WRAPPED SMOOTH TUBE ""
1328 PRINT USING "6X,""3 LPD KORODENSE TUBE ""
1329 PRINT USING "6X,""4 WIRE-WRAPPED LPD KORODENSE TUBE ""
1330 INPUT Ityp
1331 PRINTER IS 701

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132 BEEP
133 PRINTER IS 1
134 PRINT USING "4X,""Select Material Code:"""
136 PRINT USING "6X,""0 Copper      1 Stainless steel""
139 PRINT USING "6X,""2 Aluminum  3 90:10 Cu-Ni""
140 PRINT USING "6X,""4 Titanium  ""
142 INPUT Imc
145 PRINTER IS 1
148 BEEP
149 Itds=1
151 IF Iwth=0 THEN
152 PRINT USING "4X,""SELECT TUBE DIA TYPE:"""
157 PRINT USING "6X,""0  SMALL""
160 PRINT USING "6X,""1  MEDIUM (DEFAULT)""
163 PRINT USING "6X,""2  LARGE""
166 INPUT Itds
167 END IF
169 PRINTER IS 701
172 IF Iwth=0 THEN
175 D1=.0127      ! ID OF MEDIUM AND LARGE TUBES
178 Do=.01905     ! OD OF MEDIUM TUBE
183 END IF
184 IF Iwth=1 THEN
189 D1=.01347
192 Do=.01585
195 END IF
197 IF Iwth=2 THEN
198 Do=.01585
199 D1=.01386
200 END IF
201 D1=.01905
202 D2=.01587
205 IF Itds=0 THEN
206     Do=.0127
207     D1=.009525
210 END IF
211 IF Itds=2 THEN Do=.025
212 IF Iwth=1 THEN D1=.01585
213 IF Iwth=1 THEN D2=.01585
214 IF Iwth=2 THEN D1=.01587
215 IF Iwth=2 THEN D2=.01587
216 IF Imc=0 THEN Kcu=385
217 IF Imc=1 THEN Kcu=16
218 IF Imc=2 THEN Kcu=167
219 IF Imc=3 THEN Kcu=45
220 IF Imc=4 THEN Kcu=20.1

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1498 Rm=Do*LOG(Do/Di)/(2*Kcu) ! Wall resistance based on outside area
1501 BEEP
1504 INPUT "ENTER PRESSURE CONDITION (0=V,1=A)",lpc
1507 Ipc=Ipc
1508 Inf=0
1510 BEEP
1537 Ife=1
1538 PRINTER IS 701
1543 PRINT USING "16X","This analysis includes end-fin effect""
1546 PRINT USING "16X","Thermal conductivity      = ",3D.D,"" (W/m.K)"";Kcu
1549 PRINT USING "16X","Inside diameter, Di      = ",DD.DD,"" (mm)"";Di*100
1552 PRINT USING "16X","Outside diameter, Do     = ",DD.DD,"" (mm)"";Do*100
1555 BEEP
1556 Ih1=0
1557 PRINTER IS 1
1558 PRINT "      SELECT INSIDE CORRELATION:"
1559 PRINT "          0=SIDER-TATE (DEFAULT)"
1560 PRINT "          1=SLEICHER-ROUSE"
1561 PRINT "          2=PETUKHOV-POPOV"
1562 INPUT Ih1
1563 IF Ih1=0 THEN
1564 BEEP
1566 INPUT "      SELECT REYNOLDS EXPONENT",Rexp
1567 END IF
1568 Ioc=0
1569 BEEP
1570 PRINT
1571 PRINT "      SELECT OUTSIDE THEORY/CORRELATION FOR WILSON ANALYSIS:"
1572 PRINT "          0=NUSSELT THEORY (DEFAULT)"
1573 PRINT "          1=FUJII (1979) CORRELATION"
1574 INPUT Ioc
1575 BEEP
1576 Itm=1
1577 PRINT
1578 PRINT "      SELECT COOLANT TEMPERATURE RISE MEASUREMENT:"
1579 IF Istu=0 THEN PRINT "          0=SINGLE TEFLON T/C"
1580 PRINT "          1=QUARTZ THERMOMETER (DEFAULT)"
1581 PRINT "          2=10-JUNCTION THERMOPILE"
1582 INPUT Itm
1583 PRINTER IS 701
1584 IF Itm=0 THEN PRINT USING "16X","This analysis uses the SINGLE TEFLON T/C
readings""
1585 IF Itm=1 THEN PRINT USING "16X","This analysis uses the QUARTZ THERMOMETE
readings""
1586 IF Itm=2 THEN PRINT USING "16X","This analysis uses the 10-JUNCTION THERM
PILE readings""
1587 Iic=1 ! FOR MODIFIED WILSON
1588 IF Ih1=0 THEN C1=.027
1589 IF Inn=2 AND Di=.009525 THEN C1=.051 ! TO BE MODIFIED
1590 IF Inn=2 AND Di=.0127 THEN C1=.052
1591 IF Inn=3 THEN C1=.22

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192! IF Inn=0 THEN C1=.012
193! IF Ift=2 THEN C1=.035
194! END IF
195 IF Ihi=1 THEN C1=1.
196 IF Ihi=2 THEN C1=1.
197 IF Iw1=1 THEN
198 BEEP
199 INPUT "ENTER C1 IF DIFFERENT FROM STORED VALUE",C1
200 END IF
201 PRINTER IS 701
202 IF Ihi=0 THEN PRINT USING "16X","Modified Sieder-Tate coefficient = ",Z
203 IF Ihi=0 THEN PRINT USING "16X","Chosen Reynolds No. exponent = ",D
204 IF Ihi=1 THEN PRINT USING "16X","Modified Sletcher-Rouse coefficient = "
205 IF Ihi=2 THEN PRINT USING "16X","Modified Petukhov-Popov coefficient = "
206 IF Inn=0 THEN PRINT USING "16X","Using no insert inside tube""
207 IF Inn=2 THEN PRINT USING "16X","Using wire wrap insert inside tube""
208 IF Inn=3 THEN PRINT USING "16X","Using HEATEX insert inside tube""
209 IF Istu=0 THEN
210 IF Inn=1 THEN PRINT USING "16X","Using twisted tape insert inside tube""
211 ELSE
212 IF Inn=1 THEN PRINT USING "16X","Using wire wrap insert inside tube""
213 END IF
214 IF I1c=0 AND Ife=1 THEN Ac=26.4
215 IF I1c=1 THEN Ac=0.
216 BEEP
217 IF Ijob=1 THEN 1648
218 PRINTER IS 1
219 INPUT "NAME FOR A TEMPORARY PLOT FILE (TO BE PURGED)",P_file$
220 P_file$="DUMMY"
221 BEEP
222 CREATE BDAT P_file$,10
223 ASSIGN @Filep TO P_file$
224 IF Ijob=1 THEN
225 Iov=1
226 GOTO 1689
227 END IF
228 BEEP
229 INPUT "SELECT OUTPUT (0=SHORT, 1=LONG)",Iov
230 Iov=Iov+1
231 PRINTER IS 701
232 IF Ityp=0 THEN PRINT USING "16X","Tube Enhancement : SMOOTH TUBE""
233 IF Ityp=1 THEN PRINT USING "16X","Tube Enhancement : FINNED TUBE""

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1674 IF Ityp=2 THEN PRINT USING "16X, ""Tube Enhancement : WIRE-WRAPPED SMOOTH
TUBE""""
1675 IF Ityp=3 THEN PRINT USING "16X, ""Tube Enhancement : LPD KORODENSE TUBE
""
1678 IF Ityp=4 THEN PRINT USING "16X, ""Tube Enhancement : WIRE-WRAPPED LPD K
RODENSE TUBE""""
1679 BEEP
1681 IF Imc=0 THEN PRINT USING "16X, ""Tube material : COPPER""""
1682 IF Imc=1 THEN PRINT USING "16X, ""Tube material : STAINLESS-STEEL""""
1683 IF Imc=2 THEN PRINT USING "16X, ""Tube material : ALUMINUM""""
1684 IF Imc=3 THEN PRINT USING "16X, ""Tube material : 90/10 CU/NI""""
1685 IF Imc=4 THEN PRINT USING "16X, ""Tube material : TITANIUM""""
1686 IF Ipc=0 THEN PRINT USING "16X, ""Pressure condition : VACUUM""""
1687 IF Ipc=1 THEN PRINT USING "16X, ""Pressure condition : ATMOSPHERIC""""
1688 PRINT USING "16X, ""Fin pitch, width, and height (mm): "",DD.DD,2x,Z.DD,2x
Z.DD";Fp,Fw,Fh
1689 IF (Iw1=0 OR Iw1=2) AND Im=2 THEN
1690 Ijob=1
1693 Iwd=1
1696 CALL Wilson(C1)
1699 END IF
1702 J=0
1712 IF Iov=1 THEN
1722 PRINT
1723 IF Ih1=1 THEN
1724 PRINT USING "10X, ""Data Vw Uo Ho Qp Tcf Ts
Reap""""
1725 PRINT USING "10X, "" # (m/s) (W/m^2-K) (W/m^2-K) (W/m^2) (C) (C)
(S-R)""""
1726 ELSE
1728 PRINT USING "10X, ""Data Vw Uo Ho Qp T
f Ts""""
1729 PRINT USING "10X, "" # (m/s) (W/m^2-K) (W/m^2-K) (W/m^2) (
(C)""""
1730 END IF
1740 END IF
1747 Zx=0
1750 Zx2=0
1753 Zxy=0
1756 Zy=0
1759 Sx=0
1762 Sy=0
1765 Sxs=0
1768 Sxy=0
1771 Go_on=1
1774 Repeat:

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177 J=J+1
180 IF Im=1 THEN
183 BEEP
186 INPUT "LIKE TO CHECK NG CONCENTRATION (1=Y,0=N)?",Ng
189 IF J=1 THEN
192 OUTPUT 709;"AR AF40 AL41 VR5"
195 OUTPUT 709;"AS SA"
198 END IF
201 BEEP
204 INPUT "ENTER FLOWMETER READING",Fm
207 OUTPUT 709;"AR AF60 AL62 VR5"
210 OUTPUT 709;"AS SA"
213 ENTER 709;Etp
216 OUTPUT 709;"AS SA"
219 BEEP
222 INPUT "CONNECT VOLTAGE LINE",Of
225 ENTER 709;Bvol
228 BEEP
231 INPUT "DISCONNECT VOLTAGE LINE",Of
234 IF Bvol<.1 THEN
237 BEEP
240 BEEP
243 INPUT "INVALID VOLTAGE - TRY AGAIN!",Of
246 GOTO 1819
249 END IF
252 OUTPUT 709;"AS SA"
255 ENTER 709;Bamp
258 Etp=Etp*1.E+6
261 OUTPUT 709;"AR AF40 AL47 VR5"
264 Nn=7
267 FOR I=0 TO Nn
270 OUTPUT 709;"AS SA"
273 Se=0
276 FOR K=1 TO 10
279 ENTER 709;E
282 Se=Se+E
285 NEXT K
288 Emf(I)=ABS(Se/10)
291 Emf(I)=Emf(I)*1.E+6
294 NEXT I
297 OUTPUT 709;"AS SA"
300 OUTPUT 713;"T1R2E"
303 WAIT 2
306 ENTER 713;T11
309 OUTPUT 713;"T2R2E"
312 WAIT 2

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1939 ENTER 713;T2
1942 OUTPUT 713;"T1R2E"
1945 WAIT 2
1948 ENTER 713;T12
1951 T1=(T11+T12)*.5
1954 OUTPUT 713;"T3R2E"
1960 BEEP
1970 INPUT "ENTER PRESSURE GAGE READING (Pga)",Pga
1971 Pvp1=Pga*6894.7 ! PSI TO Pa
1972 OUTPUT 709;"AR AF64 AL64 VR5"
1973 OUTPUT 709;"AS 5A" ! PRESSURE TRANSDUCER
1974 Ss=0
1975 FOR K=1 TO 20
1976 ENTER 709;Etran
1977 Ss=Ss+Etran
1978 NEXT K
1979 Ptran=ABS(Ss/20)
1980 BEEP
1981 PRESSURE IN Pa FROM TRANSDUCER
1982 Pvp2=(-2.93604*Ptran+14.7827)*6894.7
1985 ELSE
1986 IF Istu=0 THEN
1989 ENTER @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvp1,Pvp2,Emf(*)
1990 ELSE
1992 ENTER @File;Bvol,Bamp,Utran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1
2,Phg,Pwater
1994 END IF
1996 IF J=1 OR J=20 OR J=Nrun THEN
1997 Ng=1
1998 ELSE
1999 Ng=0
2000 END IF
2002 END IF
2003 IF Istu=0 THEN
2008 Tsteam1=FNTvsv57(Emf(0))
2009 Tsteam1=Tsteam1-273.15
2010 Tsteam2=FNTvsv56(Emf(1))
2011 Tsteam2=Tsteam2-273.15
2012 Tsteam=Tsteam1
2015 Troom=FNTvsv58(Emf(2))
2023 Troom=Troom-273.15
2038 Tcon=FNTvsv58(Emf(7))
2039 Tcon=Tcon-273.15
2042 ELSE
2043 Tsteam=FNTvsv(Emf(0))
2044 Troom=FNTvsv(Emf(3))

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045 Tcon=FNTvsv(Emf(4))
046 END IF
048 Psat=FNpvst(Tsteam)
050 Rohg=13529-122*(Troom-26.85)/50
053 Rowater=FNrhov(Troom)
063 IF Istu=0 THEN
081 Ptest1=Pvap1
082 Ptest2=Pvap2
083 ELSE
084 Ptest2=(Phg*Rohg-Pwater*Rowater)*9.81/1000
085 END IF
087 Pks=Psat*1.E-3
088 Pkp=Ptest2*1.E-3
089 Pkt=Pks
092 Tsat=FNTvsp(Psat)
098 Vst=FNvst(Tsteam)
104 Ppng=(Ptest2-Psat)/Ptest2
121 Ppst=1-Ppng
122 Muv=18.016
123 IF Ift=1 THEN Muv=137 ! TO BE CORRECTED
124 IF Ift=2 THEN Muv=62
125 Vfng=(Ptest2-Psat)/Ptest2
126 Mfng=1/(1+(1/Vfng-1)*Muv/28.97)
127 Mfng=Mfng*100
128 Vfng=Vfng*100
131 BEEP
134 IF Iov=2 THEN
137 PRINT
138 RECORD TIME OF TAKING DATA
139 IF Im=1 THEN
140 OUTPUT 709;"TD"
141 ENTER 709;Told$
142 END IF
144 PRINT USING "10X,""Data set number" = "",DD,4X,14A";J,Told$
145 OUTPUT 709;"AP AF40 AL40 VR5"
146 OUTPUT 709;"AS SA"
149 END IF
152 IF Iov=2 AND Ng=1 THEN
155 PRINT USING "10X,"" Psat Ptran Tmeas Tsat NG %""
158 PRINT USING "10X,"" (kPa) (kPa) (C) (C) Molal ""
161 PRINT USING "11X,1(3D.DD,2X),1(3D.DD,3X),2(3D.DD,2X),2X,1(M3D.D,2X)";Pks,P
p,Tsteam,Tsat,Mfng
164 PRINT
167 END IF
170 IF Mfng<.5 THEN
173 BEEP

```

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2176 IF Im=1 AND Ng=1 THEN
2179 BEEP
2182 PRINT
2185 PRINT USING "10X,","Energize the vacuum system ""
2188 BEEP
2191 INPUT "OK TO ACCEPT THIS RUN (1=Y,0=N)?",O1
2194 IF O1=0 THEN
2197 BEEP
2200 DISP "NOTE: THIS DATA SET WILL BE DISCARDED!"
2203 WAIT 5
2206 GOTO 1780
2209 END IF
2212 END IF
2215 END IF
2218 IF Im=1 THEN
2221 IF Fm<10 OR Fm<100 THEN
2224 Ifm=0
2227 BEEP
2230 INPUT "INCORRECT FM (1=ACCEPT,0=DELETE)",Ifm
2233 IF Ifm=0 THEN 1804
2236 END IF
2239 END IF
2242! ANALYSIS BEGINS
2243 IF Istu=0 THEN
2252 T11=FNTvsv58(Emf(3))
2262 T12=FNTvsv55(Emf(5))
2272 To1=FNTvsv58(Emf(4))
2282 To2=FNTvsv55(Emf(6))
2292 T11=T11-273.15
2302 T12=T12-273.15
2312 To1=To1-273.15
2322 To2=To2-273.15
2332 Tdel1=To1-T11
2342 Tdel2=To2-T12
2352 Tdel3=T2-T1
2353 Etp1=Emf(3)+Etp/20.
2354 Dtde=2.5931E-2-1.50464E-6*Etp1+1.21701E-10*Etp12-5.1164E-15*Etp13+3.22E-19*Etp14
2355 Tris=Dtde*Etp/10.
2358 To3=T11+Tris
2359 IF Iov=2 THEN
2361 PRINT USING "1X,"," TIN1 TOUT1 TIN3 TOUT3 DELT1 DELT3 TFILE
""
2362 PRINT USING "1X,"," (TEFLON) (QUARTZ) ""
2364 PRINT USING "2X,7(3D.DD,2X)";T11,To1,T1,T2,Tdel1,Tdel3,Tris
2365 END IF

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```

367 Er1=ABS(T11-T1)
368 Er3=ABS(T12-T1)
369 PRINTER IS 1
370 BEEP
375 Er2=ABS((T2-T1)-(Tr1s))/(T2-T1)
377 IF Er2<.05 AND Im=1 THEN
378 BEEP
379 PRINT "QCT AND T-PILE DIFFER BY MORE THAN 5%"
380 Ok2=1
381 IF Ok2=0 AND Er2<.05 AND Im=1 THEN 1790
382 END IF
383 PRINTER IS 701
384 ELSE
385 T1=FNTvsv(Emf(2))
386 Grad=FNGrad((T1+T2)*.5)
387 To=T1+ABS(Etp)/(10*Grad)*1.E+6
388 T11=T1
389 To3=To
391 END IF
392 IF Istu=0 AND Itm=0 THEN
393 T11=T11
394 T2o=To1
395 END IF
396 IF Itm=1 THEN
397 T11=T1
398 T2o=T2
399 END IF
400 IF Itm=2 THEN
401 T11=T11
402 T2o=To3
403 END IF
404 Tavg=(T11+T2o)*.5
405 Ift=0
406 Cpw=FNCPw(Tavg)
407 Rhov=FNRRhov(Tavg)
408 IF Istu=0 THEN
409 Md=(6.7409*Fm+13.027)/1000.
411 Md=Md*(1.0365-1.96644E-3*T11+5.252E-6*T11^2)/1.0037
412 ELSE
413 Md=1.04805E-2+6.80932E-3*Fm
414 Md=Md*(1.0365-1.96644E-3*T11+5.252E-6*T11^2)/.995434
415 END IF
417 Mf=Md/Rhov
418 Vw=Mf/(FI*D1^2/4)
419 Vws=Vw*(D1/1.27E-2)^2
421 IF Istu=0 AND Iwth=0 THEN (SWENSEN FRIC. SMOOTH COPPER TUBE

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2422 IF Inn=0 AND Vw<.5 THEN T2o=T2o-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.96E-
Vw^3)
2423 IF Inn=1 THEN T2o=T2o-(-6.44E-5+1.71E-3*Vw+4.45E-4*Vw^2+4.07E-5*Vw^3)
2424 IF Inn=2 THEN T2o=T2o-(-3.99E-4+2.75E-3*Vw+1.45E-3*Vw^2+8.16E-5*Vw^3)
2425 IF Inn=3 THEN T2o=T2o-(-8.57E-5+1.23E-3*Vw+1.08E-3*Vw^2+8.16E-5*Vw^3)
2426 END IF
2428 IF Istu=0 AND Iwth=2 THEN !FRIC FACTOR SMTH TITANIUM TUBE
2429 IF Inn=0 AND Vw<.5 THEN T2o=T2o-(-4.62E-5-7.53E-4*Vw+1.80E-3*Vw^2-8.84E-
Vw^3)
2430 IF Inn=3 THEN T2o=T2o-(-2.09E-4+9.74E-4*Vw+2.12E-3*Vw^2-3.31E-5*Vw^3)
2431 END IF
2433 IF Istu=0 AND Iwth=1 THEN !FRICTION FACTORS FOR KORODENSE
2434 IF Inn=0 AND Vw>.5 THEN T2o=T2o-(-3.386E-4+1.88E-3*Vw+6.013E-4*Vw^2+4.13
-5*Vw^3)
2435 IF Inn=3 THEN T2o=T2o-(-2.089E-4+9.202E-4*Vw+1.893E-3*Vw^2-2.781E-5*Vw^3)
2436 END IF
2437 IF Istu=1 THEN
2439 IF Inn=0 THEN T2o=T2o-(.0138+.001*Vw^2)
2440 IF Inn=1 THEN T2o=T2o-.004*Vws^2
2441 IF Inn=2 THEN T2o=T2o-.004*Vws^2
2444 END IF
2445 Q=Md*Cpw*(T2o-T11)
2446 Qp=Q/(PI*Do*L)
2447 Ift=0
2448 h.w=FNKw(Tavg)
2449 Muw=FNMuw(Tavg)
2450 Re1=Rhow*Vw*Di/Muw ! ASSUMED SAME FOR KORODENSE
2451 Prw=FNPrw(Tavg)
2452 Fe1=0.
2453 Fe2=0.
2454 Cf=1.
2455 Prwf=Prw
2456 Reif=Re1
2461 IF Ih1=0 THEN
2463 Ome=Re1^Rexp*Prw^-.3333*Cf
2465 END IF
2466 IF Ih1=1 THEN
2467 Sra=.88-(.24/(4.+Prwf))
2468 Srb=.333333+.5*EXP(-.6*Prwf)
2470 Ome=(5.+0.15*Reif^Sra*Prwf^Srb)
2471 END IF
2472 IF Ih1=2 THEN
2473 Eps1=(1.82*LGT(Re1)-1.64)^(-2)
2474 Pp1=1.+3.4*Eps1
2475 Pp2=11.7+1.8*Prw^(-1/3)
2476 Pp1=(Eps1/8)*Re1*Prw

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177 Pp2=(Pp1+Pp12*(Eps1/8)^.5*(Prw-.6666-1))
178 Ome=Pp1/Pp2
179 END IF
181 H1=kw/D1*C1*Ome
182 IF Ife=0 THEN GOTO 2491
183 P1=PI*(Do+D1)
184 A1=(D1-D1)*PI*(D1+D1)*.5
185 M1=(H1*P1/(Kcu*A1))^.5
186 P2=PI*(D1+D2)
187 A2=(D2-D1)*PI*(D1+D2)*.5
188 M2=(H1*P2/(Kcu*A2))^.5
189 Fe1=FNtanh(M1*L1)/(M1*L1)
190 Fe2=FNtanh(M2*L2)/(M2*L2)
191 Dt=Q/(PI*D1*(L+L1*Fe1+L2*Fe2)*H1)
192 IF Ih1=0 THEN
194 Cfc=(Mw/FNMw(Tavg+Dt))^.14
195 IF ABS((Cfc-Cf)/Cfc)>.001 THEN
197 Cf=(Cf+Cfc)*.5
200 GOTO 2461
201 END IF
203 END IF
204 IF Ih1=1 THEN
205 Prwfc=FNPrw(Tavg+Dt)
206 Reifc=Vw*D1*FNRhow(Tavg+Dt)/FNMw(Tavg+Dt)
207 IF ABS((Prwfc-Prwf)/Prwfc)>.001 OR ABS((Reifc-Reif)/Reifc)>.001 THEN
208 Prwf=(Prwfc+Prwf)/2.
209 Reif=(Reifc+Reif)/2.
210 GOTO 2461
211 END IF
213 END IF
216 Ift=If to
217 Lmtd=(T2o-T11)/LOG((Tsteam-T11)/(Tsteam-T2o))
218 Uo=Q/(Lmtd*PI*Do*L)
219 Ho=1/(1/Uo-Do/L/(D1*(L+L1*Fe1+L2*Fe2)*H1)-Rm)
220 Tcf=Qp/Ho
221 Cpse=FNCPw((Tcon+Tsteam)*.5)
222 Hfg=FNHfg(Tsteam)
224 Two=Tsteam-Qp/Ho
227 Tfilm=Tsteam/3+Two*2/3
230 Kf=FNKw(Tfilm)
233 Rhof=FNRhof(Tfilm)
236 Muf=FNMuw(Tfilm)
239 Hpq=.651*Kf*(Rhof^2*9.81*Hfg/(Muf*Do*Qp))^-.3333
241 Hnuss=.728*(Kf^3*9.81*Hfg*Rhof^2/(Muf*Do*Tcf))^-.25
242 Alp1=.728*Ho/Hnuss
248 Tfm(J-1)=Tfilm
251 Qpa(J-1)=Qp

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```

2554 Y=Hpq*Qp*.3333
2557 X=Qp
2560 Sx=Sx+X
2563 Sy=Sy+Y
2566 Sxs=Sxs+X**2
2569 Sxy=Sxy+X*Y
2572 Q1=500
2575 Qloss=Q1/(100-25)*(Tsteam-Tcon) ! TO BE MODIFIED
2578 Hfc=FNHf(Tcon)
2584 Mdv=0
2587 Bp=(Bvol*100)**2/5.76
2590 Hsc=Cpsc*(Tsteam-Tcon)
2593 Mdv=((Bp-Qloss)-Mdv*Hsc)/Hfg
2596 IF ABS((Mdv-Mdv)/Mdv)>.01 THEN
2599 Mdv=(Mdv+Mdv)*.5
2602 GOTO 2593
2605 END IF
2608 Mdv=(Mdv+Mdv)*.5
2611 Vg=FNVvst(Tsteam)
2614 Vv=Mdv*Vg/Ax
2620 F=(9.81*Do*Muf*Hfg)/(Vv**2*Kf*(Tsteam-Two))
2623 Nu=Ho*Do/Kf
2626 Ret=Vv*Rhof*Do/Muf
2629 Nr=Nu/Ret*.5
2630 Hfuj=.96*(9.81*Hfg/Tcf)**.2*Kf**.8*Vv**.1*Rhof**.5/(Do*Muf)**.3
2635 IF Iov=2 THEN
2645 PRINT
2647 PRINT USING "5X,"" Vw      Re1      H1      Uo      Hfuj(DT)
      Hnu(Q)""""
2650 PRINT USING "5X,Z.DD,1X,3(MZ.3DE,1X),3X,2(MZ.3DE,3X)";Vw,Re1,H1,Uo,Hfuj,
q
2651 PRINT
2653 PRINT USING "5X,"" Vv      Ho      q      Tcf      NuRe      F
      Hnu(DT)""""
2655 PRINT USING "5X,Z.DD,1X,2(MZ.3DE,1X),2X,3D.DD,2X,3(MZ.3DE,1X)";Vv,Ho,q,
f,Nr,F,Hnuss
2656 PRINT
2658 END IF
2659 IF Iov=1 THEN
2660 IF Ih1=1 THEN
2661 PRINT USING "11X,DD,2X,Z.DD,1X,3(MD.3DE,1X),2(3D.DD,1X),D.DDD";J,Vw,Uo,H
Qp,Tcf,Tsteam,Sra
2662 ELSE
2668 PRINT USING "11X,DD,4X,Z.DD,2X,2(MD.3DE,2X),Z.3DE,3X,3D.DD,2X,3D.DD";J,V
Uo,Ho,Qp,Tcf,Tsteam
2671 END IF

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274 END IF
275 IF Im=2 THEN
284 IF (Iw1=0 AND Ijob=1) OR Iw1=0 THEN OUTPUT @Filep;Qp,Ho
294 END IF
207 BEEP
208 IF Im=1 THEN
209 IF (Iw1=0 AND Ijob=1) OR Iw1=1 THEN OUTPUT @Filep;Qp,Ho
211 INPUT "CHANGE TCOOL RISE? 1=Y, 2=N",Itr
212 IF Itr=1 THEN GOTO 2384
213 INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?",O1s
214 IF O1s=1 THEN
225 OUTPUT @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
235 Alp2=Alp1+Alp2
249 ELSE
252 J=J-1
255 END IF
258 BEEP
261 INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?",Go_on
264 Nrun=J
267 IF Go_on=0 THEN Repeat
270 ELSE
273 IF J<Nrun THEN Repeat
276 END IF
279 IF Ijob=1 THEN 2809
282 IF Iw1=0 THEN
285 ASSIGN @File TO *
288 Ijob=1
291 Iwd=1
294 CALL Wilson(Q1)
297 Im=2
300 ASSIGN @File TO D_file$
303 GOTO 1136
306 END IF
309 IF Ifg=0 THEN
312 PRINT
315 S1=(Nrun*Sxy-Sy*Sx)/(Nrun*Sxx-Sx^2)
318 Ac=(Sy-S1*Sx)/Nrun
322 PRINT USING "10X,""Least-Squares Line for Ho vs q curve:"""
324 PRINT USING "10X,"" Slope = "",MD.4DE";S1
327 PRINT USING "10X,"" Intercept = "",MD.4DE";Ac
330 END IF
333 BEEP
343 INPUT "ENTER SAME TEMPORARY PLOT FILE NAME",Fplot$
353 ASSIGN @Filep TO P_file$
363 FOR I=1 TO Nrun
373 ENTER @Filep;Qp,Ho

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```

2873 ENTER @Filep;Qp,Ho
2883 Xc=LOG(Qp/Ho)
2884 Yc=LOG(Qp)
2885 Zx=Zx+Xc
2886 Zx2=Zx2+Xc^2
2887 Zy=Yc+Yc
2888 Zy=Zy+Yc
2889 NEXT I
2890 Bb=.75
2891 Aa=EXP((Zy-Bb*Zx)/Nrun)
2892 PRINT
2893 PRINT USING "10X","Least-squares line for q = a*delta-T^b"
2894 PRINT USING "12X","a = ",MZ.4DE";Aa
2895 PRINT USING "12X","b = ",MZ.4DE";Bb
2896 IF Ift=0 THEN
2897 IF Ipc=0 THEN
2898 Qps=2.5E+5
2899 IF Iic=0 THEN Hop=9326
2902 IF Iic=1 THEN Hop=10165*(.01905/Do)^.33333
2905 END IF
2908 IF Ipc=1 THEN
2911 Qps=7.5E+5
2914 IF Iic=0 THEN Hop=7176
2917 IF Iic=1 THEN Hop=7569*(.01905/Do)^.33333
2920 END IF
2923 Hos=Aa^((1/Bb)*Qps^((Bb-1)/Bb))
2926 IF Ipc=0 THEN Aas=2.32E+4
2929 IF Ipc=1 THEN Aas=2.59E+4
2930 Alpsm=.876 !SWENSEN DATA
2931 IF Iw1=0 THEN GOTO 2959
2933 Enrat=Alp2/Alpsm
2934 Enr=Hos/Hop
2935! Enr=Aa/Aas
2938 PRINT
2941! PRINT USING "10X","Values computed at q = ",Z.DD," (MW/m^2):";Qps/1.E
6
2944! PRINT USING "12X","Heat-transfer coefficient = ",DDD.DDD," (kW/m^2.K)"
;Hos/1000
2947 PRINT USING "12X","Enhancement ratio (Del-T) = ",2D.3D;Enrat
2950! PRINT USING "10X","Enhancement ratio at constant Delta-T = ",DD.DD;Enr
2953! PRINT USING "10X","Enhancement ratio at constant q = ",DD.DD;Enr
1.3333
2956 ELSE
2959 PRINT
2962 IF Ift=1 THEN
2965 Aas=2687.2 ! ZEBROWSKI (V = 0.4 m/s)
2968 Aas=2557.0*(.01905/Do)^.33333 ! VAN PETTEN (V = 0.25 m/s)

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```

068 Aas=2557.0*(.01905/Do)'.33333 ! VAN PETTEN (U = 0.25 m/s)
071 END IF
074 IF Ift=2 THEN Aas=9269.7*(.01905/Do)'.33333
077 Edt=Aa/Aas
080 Eq=Edt^(4/3)
083 PRINT USING "10X,""Enhancement (q)      = "" ,DD.3D";Eq
086 PRINT USING "10X,""Enhancement (Del-T) = "" ,DD.3D";Edt
089 END IF
092 IF Im=1 THEN
095 BEEP
098 PRINT
001 PRINT USING "10X,""NOTE: "" ,ZZ,"" data points were stored in file "" ,10A";
D_file$
004 END IF
007 BEEP
013 PRINT
016 PRINT USING "10X,""NOTE: "" ,ZZ,"" X-Y pairs were stored in data file "" ,10
";J,Plot$
031 BEEP
073 ASSIGN @File TO *
079 ASSIGN @Filep TO *
080 PURGE "DUMMY"
094 IF Iso=2 THEN CALL Raw
100 IF Iso=3 THEN CALL Wilson(C1)
103 IF Iso=4 THEN CALL Modify
106 IF Iso=5 THEN CALL Purg
112 IF Iso=6 THEN CALL Renam
116 END
118 DEF FNPvst(Tc)
121 COM /F1d/ Ift,Istu
124 DIM K(8)
127 IF Ift=0 THEN
130 DATA -7.691234564,-26.08023696,-168.1706546,64.23285504,-118.9646225
133 DATA 4.16711732,20.9750676,1.E9,6
136 READ K(*)
139 T=(Tc+273.15)/647.3
142 Sum=0
145 FOR N=0 TO 4
148 Sum=Sum+K(N)*(1-T)^(N+1)
151 NEXT N
154 Br=Sum/(T*(1+K(5)*(1-T)+K(6)*(1-T)^2))-(1-T)/(K(7)*(1-T)^2+K(8))
157 Pr=EXP(Br)
160 P=22120000*Pr
163 END IF
166 IF Ift=1 THEN
169 Tf=Tc*1.8+32+459.6
172 P=10^((33.0655-4330.98/Tf-9.2635*LGT(Tf)+2.0539E-3*Tf)

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```

3175 P=P*101325/14.696
3178 END IF
3181 IF Ift=2 THEN
3184 A=9.394685-3066.1/(Tc+273.15)
3187 P=133.32*10^A
3190 END IF
3193 RETURN P
3196 FNEND
3199 DEF FNHfg(T)
3202 COM /Fld/ Ift,Ist
3205 IF Ift=0 THEN
3208 Hfg=2477200-2450*(T-10)
3211 END IF
3214 IF Ift=1 THEN
3217 Tf=T*1.8+32
3220 Hfg=7.0557857E+1-Tf*(4.838052E-2+1.2619048E-4*Tf)
3223 Hfg=Hfg*2326
3226 END IF
3229 IF Ift=2 THEN
3232 Tk=T+273.15
3235 Hfg=1.35264E+6-Tk*(6.38263E+2+Tk*.747462)
3238 END IF
3241 RETURN Hfg
3244 FNEND
3247 DEF FNMu(T)
3250 COM /Fld/ Ift,Ist
3253 IF Ift=0 THEN
3256 A=247.8/(T+133.15)
3259 Mu=2.4E-5*10^A
3262 END IF
3265 IF Ift=1 THEN
3268 Mu=8.9629819E-4-T*(1.1094609E-5-T*5.566829E-8)
3271 END IF
3274 IF Ift=2 THEN
3277 Tf=1/(T+273.15)
3280 Mu=EXP(-11.0179+Tf*(1.744E+3-Tf*(2.80335E+5-Tf*1.12661E+8)))
3283 END IF
3286 RETURN Mu
3289 FNEND
3292 DEF FNVvst(Tt)
3295 COM /Fld/ Ift,Ist
3298 IF Ift=0 THEN
3301 P=FNfvst(Tt)
3304 T=Tt+273.15
3307 X=1500/T
3310 F1=1/(1+T*1.E-4)

```

```

313 F2=(1-EXP(-X))2.5*EXP(X)/X1.5
316 B=.0015*F1-.000942*F2-.0004882*X
319 K=2*P/(461.52*T)
322 V=(1+(1+2*B*K)1.5)/K
325 END IF
328 IF Ift=1 THEN
331 Tf=Tt*1.8+32
334 V=13.955357-Tf*(.16127262-Tf*5.1726190E-4)
337 V=V/16.018
340 END IF
343 IF Ift=2 THEN
346 Tk=Tt+273.15
349 P=FNpvt(Tt)
352 V=133.95*Tk/P
355 END IF
358 RETURN V
361 FNEND
364 DEF FNCpw(T)
367 COM /F1d/ Ift,Ist
370 IF Ift=0 THEN
373 Cpw=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
376 END IF
379 IF Ift=1 THEN
382 Cpw=9.2507273E-1+T*(9.3400433E-4+1.7207792E-6*T)
385 END IF
388 IF Ift=2 THEN
391 Tk=T+273.15
394 Cpw=4.1868*(1.6884E-2+Tk*(3.35083E-3-Tk*(7.224E-6-Tk*7.61748E-9)))
397 END IF
400 RETURN Cpw*1000
403 FNEND
406 DEF FNRhow(T)
409 COM /F1d/ Ift,Ist
412 IF Ift=0 THEN
415 Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
418 END IF
421 IF Ift=1 THEN
424 Ro=1.6207479E+3-T*(2.2186346+T*2.3578291E-3)
427 END IF
430 IF Ift=2 THEN
433 Tk=T+273.15-338.15
436 Vf=9.24848E-4+Tk*(6.2796E-7+Tk*(9.2444E-10+Tk*3.057E-12))
439 Ro=1/Vf
442 END IF
445 RETURN Ro
448 FNEND

```

```

3451 DEF FNPrw(T)
3454 Prw=FNCPw(T)*FNMuw(T)/FNKw(T)
3457 RETURN Prw
3460 FNEND
3463 DEF FNKw(T)
3466 COM /F1d/ Ift,Istu
3469 IF Ift=0 THEN
3472 X=(T+273.15)/273.15
3475 Kw=-.92247+X*(2.8395-X*(1.8007-X*(.52577-.07344*X)))
3478 END IF
3481 IF Ift=1 THEN
3484 Kw=8.2095238E-2-T*(2.2214286E-4+T*2.3809524E-8)
3487 END IF
3490 IF Ift=2 THEN
3493 Tk=T+273.15
3496 Kw=4.1868E-4*(519.442+.320920*Tk)
3499 END IF
3502 RETURN Kw
3505 FNEND
3508 DEF FNTanh(X)
3511 P=EXP(X)
3514 Q=EXP(-X)
3517 Tanh=(P-Q)/(P+Q)
3520 RETURN Tanh
3523 FNEND
3526 DEF FNTvsv(V)
3529 COM /Cc/ C(7)
3532 T=C(0)
3535 FOR I=1 TO 7
3538 T=T+C(I)*V^I
3541 NEXT I
3544 T=T+4.73386E-3+T*(7.692834E-3-T*8.077927E-5)
3547 RETURN T
3550 FNEND
3553 DEF FNhf(T)
3556 COM /F1d/ Ift,Istu
3559 IF Ift=0 THEN
3562 hf=T*(4.203849-T*(5.88132E-4-T*4.55160317E-6))
3565 END IF
3568 IF Ift=1 THEN
3571 Tf=T*1.8+32
3574 hf=8.2078571+Tf*(.19467857+Tf*1.3214286E-4)
3577 hf=hf*2.326
3580 END IF
3583 IF Ift=2 THEN
3586 hf=250 ! TO BE VERIFIED

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```

589 END IF
592 RETURN Hf*1000
595 FNEND
598 DEF FNGrad(T)
601 Grad=37.9853+.104388*T
604 RETURN Grad
607 FNEND
610 DEF FNTvsp(P)
613 Tu=190
616 Tl=10
619 Ta=(Tu+Tl)*.5
622 Pc=FNpvst(Ta)
625 IF ABS((P-Pc)/P) < .0001 THEN
628 IF Pc<P THEN Tl=Ta
631 IF Pc>P THEN Tu=Ta
634 GOTO 3619
637 END IF
640 RETURN Ta
643 FNEND
646 DEF FNSigma(T)
649 X=647.3-T-273.15
652 S=.1160936807/((1+.83*X)+1.121404689E-3-5.75280518E-6*X+1.28627465E-8*X^2-1
14971929E-11*X^3
655 RETURN S*.001*X^2
658 FNEND
661 SUB Raw
662 COM /Fld/ Ift,Istu
664 DIM X(28)
670 INPUT "ENTER TUBE NUMBER",Itn
676 INPUT "ENTER FILE NAME",File$
679 ASSIGN @File TO File$
680 INPUT "STUDENT (0=Swensen)",Istu
681 INPUT "SMOOTH OR FINNED (0=SMOOTH, 1=FINNED)",Ifg
683 INPUT "ENTER TUBE SIZE (0=S,1=M,2=L,3=QMC)",It ds
685 INPUT "ENTER PRESSURE CONDITION (0=V,1=A)",Ipc
688 IF Ipc=0 AND Ift=0 THEN Vs=2
691 IF Ipc=0 AND Ift=2 THEN Vs=10
692 IF Ipc=1 AND Ift=0 THEN Vs=1
693 IF Ipc=1 AND Ift=1 THEN Vs=.25
694 IF Istu=1 THEN Vs=2
696 Nrun=18
700 INPUT "ENTER NUMBER OF RUNS",Nrun
703 PRINTER IS 701
706 PRINT
709 PRINT
710 IF Istu=0 THEN PRINT USING "10X","Data of Swensen"

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6715 IF Ift=0 THEN PRINT USING "10X","Vapor is steam""
6716 IF Ift=1 THEN PRINT USING "10X","Vapor is R-113""
6717 IF Ift=2 THEN PRINT USING "10X","Vapor is ethylene glycol""
6719 IF Itds=0 THEN PRINT USING "10X","Tube diameter: Small""
6720 IF Itds=1 THEN PRINT USING "10X","Tube diameter: Medium""
6721 IF Itds=2 THEN PRINT USING "10X","Tube diameter: Large""
6722 IF Itds=3 THEN PRINT USING "10X","Tube diameter: QMC""
6724 PRINT
6725 PRINT USING "10X","Tube Number: ",ZZ";Itn
6726 PRINT USING "10X","File Name: ",14A";File$
6727 IF Ifg=0 THEN PRINT USING "10X","Tube Type: Smooth""
6728 IF Ifg=1 THEN PRINT USING "10X","Tube Type: Finned""
6730 IF Ipc=0 THEN
6731 PRINT USING "10X","Pressure Condition: Vacuum""
6732 ELSE
6733 PRINT USING "10X","Pressure Condition: Atmospheric""
6734 END IF
6735 PRINT USING "10X","Vapor Velocity: ",DD.DD,"" (m/s)"";Vs
6736 ENTER @File;Ifg;Inn
6739 IF Itds=1 OR Itds=2 THEN D1=.0127
6742 IF Itds=0 OR Itds=3 THEN D1=.009525
6747 ENTER @File;Iwt,Fp,Fw,Fh
6748 IF Istu=0 AND Ifg=1 THEN
6750 Fp=Fp-1
6751 PRINT USING "10X","Fin spacing, width and height (mm): ",DD.DD,2X,Z.DD,
,Z.DD";Fp,Fw,Fh
6752 END IF
6756 PRINT
6757 PRINT USING "10X","Data Vw Tin Tout Ts""
6758 PRINT USING "10X"," # (m/s) (C) (C) (C)""
6760 PRINT
6763 FOR I=1 TO Nrun
6766 ENTER @File;X(*)
6769 Ts=FNTvsv57((X(8)+X(9))/2.)
6770 Ts=Ts-273.15
6772 Fm=X(3)
6775 T1=X(4)
6778 T2=X(5)
6781 Tavg=(T1+T2)*.5
6784 Ift=0
6785 Rhow=FNRhow(Tavg)
6787 Md=(6.7409*Fm+13.027)/1000.
6790 Md=Md*(1.0365-1.96644E-3*T1+5.252E-6*T1^2)/1.0037
6793 Mf=Md/Rhow
6796 Vw=Mf/(PI*D1^2/4)
6799 IF Inn=0 AND Vw < .5 THEN T2=T2-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.96E-5*
^3)

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```

809 IF Inn=1 THEN T2=T2-(-6.44E-5+1.71E-3*Uw+4.45E-4*Uw^2+4.07E-5*Uw^3)
810 IF Inn=2 THEN T2=T2-(-3.99E-4+2.75E-3*Uw+1.45E-3*Uw^2+8.16E-5*Uw^3)
811 IF Inn=3 THEN T2=T2-(8.57E-5+1.23E-3*Uw+1.08E-3*Uw^2+8.16E-5*Uw^3)
814 PRINT USING "10X,DD,5X,D.DD,3X,2(DD.DD,3X),DDD.DD";I,Uw,T1,T2,Ts
817 NEXT I
820 ASSIGN @File TO *
823 SUBEND
826 SUB Wilson(C1)
829 COM /Wil/ Nrun,Itm,Iwth,Imc,Ife,Ijob,Iwd,Ifg,Ipc0,Ift0,Iw1,Ih1,Ioc,Inam,K
u,Rexp,Rm
832 COM /Fld/ Ift,Istu
833 COM /Geom/ D1,D2,D1,Do,L,L1,L2
835 DIM Emf(20),Bvo(25),Bam(25),Eata(25),Ear(25,7),Fma(25),T1a(25),T2a(25)
845 IF Ioc=0 THEN
847 PRINT USING "16X,""Nusselt theory is used for Ho""
848 ELSE
849 PRINT USING "16X,""Fujii correlation used for Ho""
850 END IF
853 BEEP
856 INPUT "RE-ENTER DATA FILE BEING PROCESSED",D_file$
859 BEEP
862 INPUT "GIVE A NAME FOR XY PLOT-DATA FILE",Plot$
865 CREATE BDAT Plot$,10
868 ASSIGN @Io_path TO Plot$
871 Jj=0
874 ASSIGN @File TO D_file$
877 ENTER @File;Ifg,Inn
878 IF Istu=0 THEN
883 ENTER @File;Ddd,Ddd,Ddd,Ddd
884 ELSE
885 IF Ifg=0 THEN ENTER @File;Iwt
886 IF Ifg=1 THEN ENTER @File;Fp,Fw,Fh
887 END IF
888 IF Jj=0 THEN
895 IF Ih1=0 THEN C1=.027
896 IF Ih1=1 THEN C1=1.00
897 IF Ih1=2 THEN C1=1.00
899 IF Ifg=0 THEN Alp=1.2
900 IF Ifg=1 THEN Alp=2.6
901 IF Ift=2 AND Ifg=1 THEN Alp=5.0
904 END IF
907 J=0
910 Sx=0
913 Sy=0
916 Sx.s=0
919 Sx.y=0

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```

6922) READ DATA FROM A USER-SPECIFIED FILE IF INPUT MODE (Im) = 2
6925 IF Jj=0 THEN
6926 IF Istu=0 THEN
6931 ENTER @File;Bvol,Bamp,Etp,Fm,T1,T2,Ddd,Ddd,Emf(*)
6932 ELSE
6934 ENTER @File;Bvol,Bamp,Utran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1
2,Phg,Pwater
6936 END IF
6938 Bvo(J)=Bvol
6939 Bam(J)=Bamp
6940 Eata(J)=Etp
6943 Ear(J,0)=Emf(0)
6946 Ear(J,1)=Emf(1)
6949 Ear(J,2)=Emf(2)
6952 Ear(J,3)=Emf(3)
6955 Ear(J,4)=Emf(4)
6956 IF Istu=1 THEN GOTO 6961
6958 Ear(J,5)=Emf(5)
6959 Ear(J,6)=Emf(6)
6960 Ear(J,7)=Emf(7)
6961 Fma(J)=Fm
6962 T1a(J)=T1
6964 T2a(J)=T2
6967 ELSE
6970 Bvol=Bvo(J)
6973 Bamm=Bam(J)
6976 Etp=Eata(J)
6979 Emf(0)=Ear(J,0)
6982 Emf(1)=Ear(J,1)
6985 Emf(2)=Ear(J,2)
6988 Emf(3)=Ear(J,3)
6991 Emf(4)=Ear(J,4)
6992 IF Istu=1 THEN GOTO 6997
6994 Emf(5)=Ear(J,5)
6995 Emf(6)=Ear(J,6)
6996 Emf(7)=Ear(J,7)
6997 Fm=Fma(J)
6998 T1=T1a(J)
7000 T2=T2a(J)
7003 END IF
7004 IF Istu=0 THEN
7006 Tsat=FNTvsv57((Emf(0)+Emf(1))/2.)
7007 Tsat=Tsats-273.15
7009 T1=FNTvsv58(Emf(3))
7010 T01=FNTvsv58(Emf(4))
7012 T1=T1-273.15

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```

013 To1=To1-273.15
015 Etp1=Emf(3)+Etp/20.
016 Dtd=2.5931E-2-1.50464E-6•Etp1+1.21701E-10•Etp12-5.1164E-15•Etp13+3.2201
-19•Etp14
017 Tris=Dtd•Etp/10.
018 To=T1+Tris
019 ELSE
020 Tsat=FNTvsv(Emf(0))
021 T1=FNTvsv(Emf(2))
022 Grad=FNGrad((T1+T2)•.5)
023 To=T1+ABS(Etp)/(10•Grad)•1.E+6
024 END IF
025 CALCULATE THE LOG-MEAN-TEMPERATURE DIFFERENCE
026 IF Istu=0 AND Itm=0 THEN
027 Tf=T1
028 Tl=To1
029 END IF
030 IF Itm=1 THEN
031 Tf=T1
032 Tl=T2
033 END IF
034 IF Itm=2 THEN
035 Tf=T1
036 Tl=To
037 END IF
038 Tavg=(Tf+Tl)•.5
039 Trise=Tl-Tf
040 Lmtd=Trise/LOG((Tsat-Tf)/(Tsat-Tl))
041 Ift=0
042 Cpw=FNCPw(Tavg)
043 Rhov=FNRRhov(Tavg)
044 Kw=FNKw(Tavg)
045 Muwa=FNMuw(Tavg)
046 Prw=FNPrw(Tavg)
047 Ift=Ifto
048 IF Istu=0 THEN
049 Mdt=(6.7409•Fm+13.027)/1000.
050 Md=Mdt•(1.0365-Tf•(1.96644E-3-Tf•5.252E-6))/1.0037
051 ELSE
052 Mdt=1.04805E-2+6.80932E-3•Fm
053 Md=Mdt•(1.0365-Tf•(1.96644E-3-Tf•5.252E-6))/.995434
054 END IF
055 Vf=Md/Rhov
056 Vw=Vf/(PI•D12/4)
057 Vws=Vw•(D1/1.27E-2)2
058 IF Istu=0 AND Iwth=0 THEN ISWENSEN FRICTION FAC. FOR COPPER TUBE

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7075 IF Inn=0 AND Vw<.5 THEN Trise=Trise-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.9E-5*Vw^3)
7078 IF Inn=1 THEN Trise=Trise-(-6.44E-5+1.71E-3*Vw+4.45E-4*Vw^2+4.07E-5*Vw^3)
7079 IF Inn=2 THEN Trise=Trise-(-3.99E-4+2.75E-3*Vw+1.45E-3*Vw^2+8.16E-5*Vw^3)
7080 IF Inn=3 THEN Trise=Trise-(8.57E-5+1.23E-3*Vw+1.08E-3*Vw^2+8.16E-5*Vw^3)
7081 END IF
7083 IF Istu=0 AND Iwth=2 THEN !KREEFE FRIC. FAC. FOR SMOOTH TITANIUM TUBE.
7085 IF Inn=0 AND Vw<.5 THEN Trise=Trise-(-4.62E-5-7.53E-4*Vw+1.80E-3*Vw^2-6.8E-5*Vw^3)
7086 IF Inn=3 THEN Trise=Trise-(2.09E-4+9.74E-4*Vw+2.12E-3*Vw^2-3.31E-5*Vw^3)
7087 END IF
7088 IF Istu=0 AND Iwth=1 THEN !FRICTION FACTORS FOR KORODENSE
7089 IF Inn=0 AND Vw>.5 THEN Trise=Trise-(-3.386E-4+1.88E-3*Vw+6.013E-4*Vw^2+4.133E-5*Vw^3)
7090 IF Inn=3 THEN Trise=Trise-(2.089E-4+9.202E-4*Vw+1.893E-3*Vw^2-2.781E-5*Vw^3)
7091 END IF
7092 IF Istu=1 THEN
7093 IF Inn=0 THEN Trise=Trise-(.0138+.001*Vw^2)
7094 IF Inn=1 THEN Trise=Trise-.004*Vws^2
7095 IF Inn=2 THEN Trise=Trise-.004*Vws^2
7100 END IF
7108 Q=Md*Cpw*Trise
7111 Qp=Q/(PI*Do*L)
7114 Uo=Qp/Lmtd
7117 Re=Rhow*Uw*Di/Muwa
7120 Fe1=0
7123 Fe2=0
7126 Cf=1.
7127 Prwf=Prw
7128 Reif=Re
7129 Ift=0
7131 Two=Tsats-5
7132 Tfilm=Tsats/3+Two*2/3
7135 Kf=FNKw(Tfilm)
7138 Rhof=FNRRhow(Tfilm)
7141 Muf=FNMuw(Tfilm)
7144 Hfgp=FNHfg(Tsats)+.68*FNCpw(Tfilm)*(Tsats-Two)
7147! New=Kf*(Rhof^2*9.81+Hfgp/(Muf*Do*Qp))^-.3333
7148 New=(Kf^3*9.81+Hfgp*Rhof^2/(Muf*Do*(Tsats-Two)))^-.25
7150 IF Ioc=1 THEN
7153! New=Kf*((9.81+Hfgp/Qp)^.25)*((Muf*Do)^(-.375))*(Rhof^-.625)*(Vw^-.125)
7154 New=(9.81+Hfgp/(Tsats-Two))^-.2*Kf^-.8*Vw^-.1*Rhof^-.5/(Do*Muf)^.3
7156 END IF
7159 Ho=Alp*New
7162 Twoc=Tsats-Qp/Ho

```

```

165 IF ABS((Twoc-Two)/Two) > .001 THEN
168 Two=Twoc
171 GOTO 7132
174 END IF
175 Rexp1=Rexp
184 IF Ih1=0 THEN
186 Omega=Re Rexp1*Prw1.3333*Cf
187 END IF
188 IF Ih1=1 THEN
189 Sra=.88-(.24/(4.+Prwf))
190 Srb=.333333+.5*EXP(-6*Prwf)
191 Omega=(5+.015*Re1fSra*PrwfSrb)
192 END IF
193 IF Ih1=2 THEN
194 Eps1=(1.82*LOG(Re)-1.64)(-2)
195 Ppk1=1.+3.4*Eps1
196 Ppk2=11.7+1.8*Prw(-1/3)
197 Pp1=(Eps1/8)*Re*Prw
198 Pp2=(Ppk1+Pp12*(Eps1/8)1.5*Prw(.6666-1))
199 Omega=Pp1/Pp2
200 END IF
202 H1=Kw/D1*C1*Omega
203 IF Ife=0 THEN 7216
204 P1=PI*(D1+D1)
205 P2=PI*(D1+D2)
206 A1=(D1-D1)*PI*(D1+D1).5
207 A2=(D2-D1)*PI*(D1+D2).5
208 M1=(H1*P1/(Kcu*A1)).5
209 M2=(H1*P2/(Kcu*A2)).5
210 Fe1=FNtanh(M1*L1)/(M1*L1)
213 Fe2=FNtanh(M2*L2)/(M2*L2)
216 Dt=Q/(PI*D1*(L+L1*Fe1+L2*Fe2)*H1)
217 IF Ih1=0 THEN
219 Muw1=FNMuw(Tavg+Dt)
222 Cfc=(Muwa/Muw1)1.14
225 IF ABS((Cfc-Cf)/Cfc) > .001 THEN
226 Cf=(Cf+Cfc).5
231 GOTO 7184
232 END IF
233 END IF
235 IF Ih1=1 THEN
236 Prwfc=FNPrw(Tavg+Dt)
237 Re1fc=Vw*D1*FNrho1(Tavg+Dt)/FNMuw(Tavg+Dt)
239 IF ABS((Prwfc-Prwf)/Prwfc) > .001 OR ABS((Re1fc-Re1f)/Re1fc) > .001 THEN
240 Prwf=(Prwfc+Prwf)/2.
241 Re1f=(Re1fc+Re1f)/2.

```

```

7242 GOTO 7184
7243 END IF
7245 END IF
7246 Ift=Ifto
7247 X=Do*New*L/(Omega*kw*(L+L1*Fe1+L2*Fe2))
7248 Y=New*(1/Uo-Rm)
7249 COMPUTE COEFFICIENTS FOR THE LEAST-SQUARES-FIT STRAIGHT LINE
7250 IF Jp=1 THEN OUTPUT @Io_path;X,Y
7252 Sx=Sx+X
7255 Sy=Sy+Y
7258 Sxs=Sxs+X*X
7261 Sxy=Sxy+X*Y
7264 IF Im=1 AND Jj=0 THEN OUTPUT @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Em
*)
7267 J=J+1
7270 IF J<Nrun THEN 6925
7273 S1=(Nrun*Sxy-Sy*Sx)/(Nrun*Sxs-Sy^2)
7276 IF Iw1=2 THEN
7279 IF Inn=1 AND D1=.009525 THEN S1=1/.051 !TO BE MODIFIED
7282 IF Inn=0 THEN S1=1/.012
7283 IF Inn=3 THEN S1=1/.22
7285 IF Inn=1 AND D1=.0127 THEN S1=1/.052
7286 IF Ift=2 THEN S1=1/.035
7287 IF Ih1=0 THEN S1=1/.027
7288 IF Ih1=1 THEN S1=1/1.00
7289 IF Ih1=2 THEN S1=1/1.00
7291 END IF
7294 Ac=(Sy-S1*Sx)/Nrun
7297 C1c=1/S1
7300 Alpc=1/Ac
7303 Jj=Jj+1
7306 IF Jp=1 THEN Jp=2
7309 Cerr=ABS((C1c-C1)/C1c)
7312 Aerr=ABS((Alpc-Alp)/Alpc)
7315 IF Cerr>.001 OR Aerr>.001 THEN
7318 C1=(C1c+C1)*.5
7321 Alp=(Alpc+Alp)*.5
7324 BEEP
7327 IF Ijob=1 THEN 6907
7330 ELSE
7333 IF Jp=0 THEN Jp=1
7336 END IF
7339 IF Jp=1 THEN 6874
7342 C1=(C1+C1c)*.5
7345 PRINT
7346 IF Ih1=0 THEN

```

```

348 PRINT USING "10X,""C1 (based on Sieder-Tate)      =  "",Z.4D";C1
349 END IF
350 IF Ih1=1 THEN
351 PRINT USING "10X,""C1 (based on Sleigher-Rouse)    =  "",Z.4D";C1
352 PRINT USING "10X,""Re exponent for Sleigher-Rouse =  "",D.DDD";Sra
353 END IF
354 IF Ih1=2 THEN
355 PRINT USING "10X,""C1 (based on Petukhov-Popov)    =  "",Z.4D";C1
356 END IF
357 IF Ioc=0 THEN
358 PRINT USING "10X,""Alpha (based on Nusselt (Tdel)) =  "",Z.4D";Alp
359 END IF
360 IF Ioc=1 THEN
361 PRINT USING "10X,""Alpha (based on Fujii (Tdel))    =  "",Z.4D";Alp
362 END IF
363 IF Inam=5 THEN
364 IF Ih1=0 THEN
366 IF Ipco=0 AND Inn=0 THEN Alpsm=.8218  INO INSERT,VACUUM,S-T
367 IF Ipco=1 AND Inn=0 THEN Alpsm=.7793  INO INSERT,ATMOSPHERIC,S-T
368 IF Ipco=0 AND Inn=3 THEN Alpsm=.7854  IHEATEX,VACUUM,S-T
369 IF Ipco=1 AND Inn=3 THEN Alpsm=.7789  IHEATEX,ATMOSPHERIC,S-T
371 END IF
372 IF Ih1=1 THEN
373 IF Ipco=0 AND Inn=0 THEN Alpsm=.8613  INO INSERT,VACUUM,S-R
374 IF Ipco=1 AND Inn=0 THEN Alpsm=.8218  INO INSERT,ATMOSPHERIC,S-R
375 IF Ipco=0 AND Inn=3 THEN Alpsm=.7791  IHEATEX,VACUUM,S-R
376 IF Ipco=1 AND Inn=3 THEN Alpsm=.7929  IHEATEX,ATMOSPHERIC,S-R
378 END IF
379 IF Ih1=2 THEN
380 IF Ipco=0 AND Inn=0 THEN Alpsm=.8205  INO INSERT,VACUUM,P-P
381 IF Ipco=1 AND Inn=0 THEN Alpsm=.7654  INO INSERT,ATMOSPHERIC,P-P
382 IF Ipco=0 AND Inn=3 THEN Alpsm=.7670  IHEATEX,VACUUM,P-P
383 IF Ipco=1 AND Inn=3 THEN Alpsm=.7708  IHEATEX,ATMOSPHERIC,P-P
385 END IF
386 END IF
387 IF Inam=4 THEN
390 IF Ipco=1 THEN Alpsm=.676  ISWENSEN DATA BASED ON DEL-T
391 END IF
392 IF Inam=0 OR Inam=3 THEN
393 IF Ipco=0 THEN Alpsm=.83  IVP M1STU103
394 IF Ipco=1 THEN Alpsm=.88  IVP SMTHSTA65
396 IF Ift=1 THEN Alpsm=.733  IZEBROWSKI (V = 0.45 m/s)
397 IF Ift=1 THEN Alpsm=.677  IVAN PETTEN (V = 0.25 m/s)
398 IF Ift=2 THEN Alpsm=1.262
399 END IF
401 IF Inam=1 THEN  IMITROU ALPHA FOR P-P FROM REPROCESSING

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```

7402 IF Ipco=0 THEN Alpsm=.8437
7403 IF Ipco=1 THEN Alpsm=.8418
7404 END IF
7405 Et=Alp/Alpsm
7406 Eq=Et^1.333333
7407 PRINT USING "10X","Enhancement (q)           = ",DD.3D";Eq
7408 PRINT USING "10X","Enhancement (Del-T)       = ",DD.3D";Et
7409 ASSIGN @File TO *
7410 SUBEND
7519 SUB Modify
7520 COM /Fld/ Ift,Istu
7522 DIM Emf(20)
7525 BEEP
7528 INPUT "ENTER NAME OF FILE TO BE MODIFIED",Fileo$
7531 ASSIGN @Fileo TO Fileo$
7534 CREATE BDAT "TEST",30
7537 ASSIGN @Filed TO "TEST"
7540 ENTER @Fileo;Ifg,Inn
7543 OUTPUT @Filed;Ifg,Inn
7544 IF Istu=0 THEN
7546 ENTER @Fileo;Iwt,Fp,Fw,Fh
7547 OUTPUT @Filed;Iwt,Fp,Fw,Fh
7548 ELSE
7549 IF Ifg=0 THEN
7551 ENTER @Fileo;Iwt
7552 OUTPUT @Filed;Iwt
7553 END IF
7554 IF Ifg=1 THEN
7555 ENTER @Fileo;Fp,Fw,Fh
7556 OUTPUT @Filed;Fp,Fw,Fh
7557 END IF
7559 END IF
7560 BEEP
7561 INPUT "ENTER NUMBER OF DATA SETS STORED",N
7562 FOR I=1 TO N
7563 IF Istu=0 THEN
7565 ENTER @Fileo;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
7566 ELSE
7567 ENTER @Fileo;Bvol,Bamp,Utran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T
T2,Phg,Pwater
7568 END IF
7570 PERFORM CORRECTIONS
7571 PRINT USING "2X","DO YOU WISH TO DELETE POINT",DD,""?"";I
7572 INPUT "0=YES, 1=NO",Idel
7573 IF Idel=0 THEN 7580
7576 IF Istu=0 THEN

```

```

577 OUTPUT @Filed;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
578 ELSE
579 OUTPUT @Filed;Bvol,Bamp,Utran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1
580 U2,Phg,Pwater
581 END IF
582 NEXT I
583 ASSIGN @Fileo TO *
584 ASSIGN @Filed TO *
585 SUBEND
586 SUB Purg
587 BEEP
591 INPUT "ENTER FILE NAME TO BE DELETED",File$
594 PURGE File$
597 GOTO 7588
600 SUBEND
601 SUB Renam
602 BEEP
606 INPUT "ENTER FILE NAME TO BE RENAMED",File1$
609 BEEP
702 INPUT "ENTER NEW NAME FOR FILE",File2$
705 RENAME File1$ TO File2$
708 GOTO 7693
711 SUBEND
721 DEF FNTvsv55(V)
731 COM /Cc55/ T55(5)
741 T=T55(0)
751 FOR I=1 TO 5
761 T=T+T55(I)*V^I
771 NEXT I
781 RETURN T
791 FNEND
801 DEF FNTvsv56(V)
811 COM /Cc56/ T56(5)
821 T=T56(0)
831 FOR I=1 TO 5
841 T=T+T56(I)*V^I
851 NEXT I
861 RETURN T
871 FNEND
881 DEF FNTvsv57(V)
891 COM /Cc57/ T57(5)
901 T=T57(0)
911 FOR I=1 TO 5
921 T=T+T57(I)*V^I
931 NEXT I
941 RETURN T
951 FNEND
961 DEF FNTvsv58(V)
971 COM /Cc58/ T58(5)
981 T=T58(0)
991 FOR I=1 TO 5

```

```
8001  T=T+T58(I)*V I  
8011  NEXT I  
8021  RETURN T  
8031  FNEND
```

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